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MONTHLY WEATHER REVIEW

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VOLUME 83 NUMBER 5

MAY 1955

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The issue for each month is published as promptly as monthly data can be assembled for preparation of the review of the weather of the month. In order to maintain the schedule with the Public Printer, no proofs will be sent to authors outside of Washington, D. C.

The printing of this publication has been approved by the Director of the Bureau of the Budget, February 9, 1955

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DEPARTMENT OF COMMERCE
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WEATHER BUREAU
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MONTHLY WEATHER REVIEW

JAMES E. CASKEY, JR., Editor

Volume 83
Number 5

MAY 1955

Closed July 15, 1955
Issued August 15, 1955

VARIATIONS IN THE INTENSITY OF SOLAR RADIATION AT NORMAL INCIDENCE ON THE SURFACE OF THE EARTH

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[Manuscript received December 22, 1954; revised March 17, 1955]

This paper brings up to date three earlier summaries by Kimball [1 and 2] and Hand [3] of variations in the intensity of solar radiation at normal incidence on the earth's surface. The data summarized here are taken from stations in the United States only as in the previous paper by Hand, whereas Kimball used world-wide data. However, due to the incompleteness of data, this paper could not be based precisely on the same stations used by Hand. It is based instead on all available data for 1939–1952 for Blue Hill Observatory, Mass., Madison, Wis., Lincoln, Nebr., Table Mountain, Calif., Albuquerque N. Mex., and Boston, Mass.

Pyrheliometric measurements of normal incidence radiation are made at frequent intervals at selected stations only when the sky in front of the sun is cloudless. Commencing with Madison, Wis. in 1910 and continuing with Lincoln, Nebr. 1915; Blue Hill, Mass. 1932; Albuquerque, N. Mex., 1941; Boston, Mass., 1945; and Table Mountain, Calif., 1947, monthly normals for each principal air mass, for each station have been maintained. The sum of the monthly values of each air mass added to the accumulated total of that particular air mass since the station's inception is divided by the total number of observations over this period, thus obtaining a running normal. Dividing the actual monthly mean value by the running normal for each air mass, and multiplying by 100, the percent of normal for the month for the air mass was determined. The average of the percent of normal of the principal air masses was taken as the monthly percent of normal before smoothing. Next, these percents were smoothed by the formula $(a+2b+c)/4$ where b is the percent of normal for the current month, and a and c for the preceding and following months. The smoothed curves for all stations combined and for each station individually are shown in figure 1. The data for all stations combined are also given in table 1. Figure 1 and table 1 also give the yearly averages.

It is interesting to speculate on the causes of some of the major variations in the curves of figure 1. Normal incidence insolation is attenuated in various ways before its receipt at the surface of the earth. Perhaps the most important and certainly the one with the most lasting effect is the presence of minute particles of volcanic dust, suspended in the atmosphere, usually produced by a violent volcanic eruption. Months and sometimes years are required before these particles settle to the ground, as shown in the solar radiation measurements for the years after the eruption of Krakatoa in 1883 [1 and 4]. From 1939 to 1952 just one known instance of volcanic dust occurred over the United States, and this was confined to the eastern section, reaching as far west as New Orleans and as far north as Boston, in June 1951. This volcanic dust, observed first over the Caribbean [5], was from an eruption in the Cape Verde Islands. Cloudiness at Blue Hill Observatory prevented any solar observations of this phenomenon, and no other recording station was in the area affected by this dust. However, shortly after this time a depression appeared in the curve for Blue Hill and continued until January 1952.

A second and more frequent vitiation in the form of smoke and haze, although of short duration, depletes insolation to a very marked degree. By far the greatest number of negative deviations during this period were caused by the presence of smoke and haze, usually local

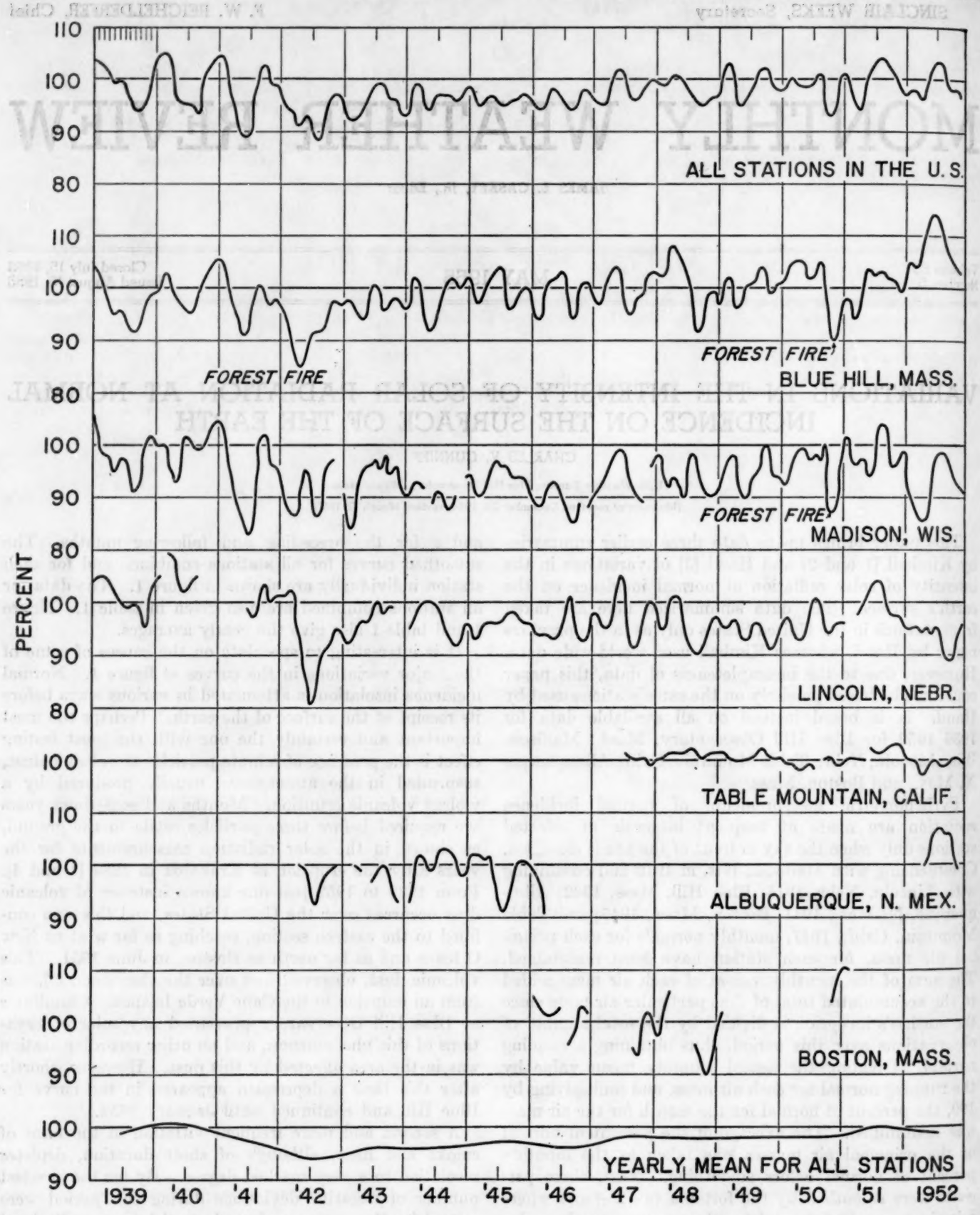

FIGURE 1.—Smoothed percents of normal solar radiation at normal incidence at stations in the United States, 1939–1952. The first seven curves are based on monthly percents of normals; the final curve is based on the yearly means of the monthly values. Vertical grid lines indicate January of each year; center ticks, July. Monthly spacing is indicated by ticks in upper left corner.

TABLE 1.—*Percents of normal incidence radiation at all stations* in the United States, 1939–1952*

	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	Average
January	105	101	106	97	94	93	99	98	97	100	97	97	101	98	99
February	103	102	104	96	91	96	97	95	95	97	99	98	101	97	98
March	101	102	100	94	94	99	95	94	96	99	100	99	95	98	98
April	100	102	95	90	96	98	97	97	97	102	97	99	97	96	97
May	98	99	91	92	96	96	98	99	101	100	95	99	99	99	97
June	98	99	88	94	97	95	98	97	102	98	96	98	100	101	97
July	98	100	92	89	99	97	97	95	99	99	97	99	102	102	97
August	95	100	95	89	99	97	97	92	95	97	98	101	103	101	97
September	94	99	101	93	98	97	97	94	95	95	100	98	103	99	97
October	95	101	101	95	97	96	98	95	95	94	100	94	101	99	97
November	96	102	98	97	96	93	98	99	99	95	96	95	99	98	97
December	100	104	98	97	95	97	97	96	100	96	97	98	99	97	98
Mean	99	101	97	94	96	96	97	96	98	98	98	98	100	99	
Departure	−01	+01	−03	−06	−04	−04	−03	−04	−02	−02	−02	−02	00	−01	

*Data from following stations: Blue Hill Observatory, Mass., Madison, Wis., Lincoln, Nebr., Table Mountain, Calif., Albuquerque, N. Mex., and Boston, Mass.

in nature and origin. These vitiations often occur with the presence of a subsiding high pressure system when smoke, haze, and traffic dust of the cities are trapped by a temperature inversion aloft.

A very important source of smoke that prevents the passage of solar radiation through the atmosphere is forest fires. Smoke from these fires may be lifted to the tropopause and may travel for great distances. In late September 1950, a forest fire [6 and 7] occurred in northwest Canada, and a week later evidence of this smoke was found as far east as Germany and Poland. Smoke of this magnitude and density has practically the same effect on insolation as a thin water vapor cloud [8] and radiation values at Blue Hill and Madison for September and October showed sharp declines as a result.

Dust storms, another factor in the depletion of solar energy, of the intensity of those in the spring of 1934 [9] in South Central United States, have not been encountered during the 1939–1952 period. There is no evidence of any important depletion of solar energy as a result of dust storms during this period.

Explanations of minor fluctuations in the curves cannot be attempted here; however for the more radical departures the following causes are suggested as possibilities. A sharp depression in the curve for all stations combined occurred beginning in January 1941 and climaxing in June 1941. This drop was due for the most part to forest fires at Blue Hill, and persistent smoke and haze at both Blue Hill and Madison. From October 1941 to May 1947, values of normal incidence radiation were consistently lower than average. The increase in manufacturing, and the conversion from oil to soft coal by many homes and factories during World War II may have contributed greatly to these depletions. It was during this period, in August 1942, that the greatest departure from normal took place since the eruption of Katmai in 1912.

The possibility that some of the air mass readings at Madison and Blue Hill were taken through thin clouds is not remote. At Madison over the period July 1941 to October 1947 solar halos were recorded on 27 different days on which normal incidence measurements were also made. Although it is not possible to determine whether or not thin clouds were present at the air mass times, it is possible that on some occasions they did coincide. At Blue Hill it was common practice to take normal incidence readings from any smooth curve, and over this period it is a distinct possibility that in some few measurements the radiation was attenuated by clouds.

REFERENCES

1. H. H. Kimball, "Volcanic Eruptions and Solar Radiation Intensities," *Monthly Weather Review*, vol. 46, No. 9, August 1918, pp. 355–356.
2. H. H. Kimball, "Variations in Solar Radiation Intensities Measured at the Surface of the Earth," *Monthly Weather Review*, vol. 52, No. 11, November 1924, pp. 527–529.
3. Irving F. Hand, "Variation in Solar Radiation Intensities at the Surface of the Earth in the United States," *Monthly Weather Review*, vol. 67, No. 9, September 1939, pp. 338–340.
4. H. Wexler, "On the Effects of Volcanic Dust on Insolation and Weather," *Bulletin of the American Meteorological Society*, vol. 32, No. 1, January 1951, pp. 10–15.
5. W. F. Brown, "Volcanic Ash Over the Carribbean, June 1951," *Monthly Weather Review*, vol. 80, No. 4, April 1952, pp. 59–62.
6. H. Wexler, "The Great Smoke Pall of Sept. 24–30, 1950," *Weatherwise*, vol. 3, No. 6, December 1950, pp. 129–135.
7. C. D. Smith, "The Widespread Smoke Layer From Canadian Forest Fires During Late September 1950," *Monthly Weather Review*, vol. 78, No. 9, September 1950, pp. 180–184.
8. Rudolf Penndorf, "On the Phenomenon of the Colored Sun, Especially the 'Blue' Sun of September 1950," *Geophysical Research Papers* No. 20, Air Force Cambridge Research Center, Cambridge, Mass., April 1953.
9. Irving F. Hand, "The Character and Magnitude of the Dust Cloud which Passed over Washington, D. C., May 11, 1934," *Monthly Weather Review*, vol. 62, No. 5, May 1934, pp. 156–157.

THE WEATHER AND CIRCULATION OF MAY 1955 [1]

Alleviation of Drought in the Midwest

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1. INTRODUCTION

Drought-breaking rains in the Great Plains and a continuation of unseasonably cool weather in the Far West (the sixth successive month) were the principal items of weather news during May. Drying winds and subnormal precipitation during March and April had depleted soil moisture over the Great Plains to the point where the crop prospects were seriously impaired. This trend, however, was completely reversed the latter part of the month when heavy extensive rains occurred which gave rise to considerable flooding.

2. THE MEAN CIRCULATION

The mean circulation for the month (fig. 1) contained a well developed westerly flow in the Pacific, a depressed but strong westerly flow in the Atlantic, and a somewhat weaker than normal westerly regime over North America. The Aleutian Low was quite near its normal position but more intense than usual with heights some 180 ft. below normal. Between this center and the zonal band of positive departures to the south (roughly parallel latitude 35°), the westerlies were up to 6 m. p. s. stronger than normal (fig. 2B). To the south of this strong subtropical ridge and in the region just north of the Hawaiian Islands, the easterlies were similarly enhanced by maximum values of 5 m. p. s.

The strong westerly flow in the eastern portion of the Pacific was instrumental in introducing repeated surges of maritime Pacific air into the mean trough in the western United States. These contributed to the unseasonably cool weather in that area which was characteristic of the entire month.

Over the United States the mean trough in the West (fig. 1) was observed well inland and extended from Idaho to southern California. The southern portion of this trough was situated approximately in its normal position but the portion over Idaho was located in a position where mean troughs are infrequently observed. In fact this area is normally occupied by a mean ridge. In the East, heights were everywhere above normal with the mean ridge line roughly parallel to the Appalachians. This pattern (trough in the West—ridge in the East) resembles that for April and has been typical of the Spring season as a whole.

In the western Atlantic, a blocking regime centered in the southern Davis Straits was effective in shifting the westerly jet well south of its customary May axis. This point can best be discerned from figure 2B which shows that departures above normal wind speed reached 6 m. p. s., equal to the maximum departure in the Pacific. Equal and opposite departures are noted in the vicinity of Greenland which was a region of exceptionally light wind movement during this month.

Typical of blocking regimes were the negative height departures from normal which were observed at middle latitudes in the western Atlantic to the southeast of the seat of blocking in the Davis Straits. Less typical however, was the anomaly of +120 ft. found to its southwest over the Great Lakes. It may be noted that this relationship was also present for the first half month (fig. 3A) even though the blocking activity was much stronger on that occasion as evidenced by the anomaly of +320 ft. in the Davis Straits. Thus, in this instance, the blocking was not effective in preventing ridging and positive anomalies over the eastern United States, a circumstance which was important in accounting for this month's warm temperature regime in the East. In the latter half of the month (fig. 3B) the blocking over Canada diminished and gradually extended its influence westward with a double anomaly center developing—one of +200 ft. in southern Greenland and the other of +160 ft. in southwestern Hudson Bay. This time, however, the latter was associated with the more usual negative anomaly on its southwestern side—heights were below normal over the south-central United States. This combination was associated with slow-moving storms well south of the normal track. These produced the heavy rains which were so badly needed to alleviate the worsening drought in the Plains area.

The presence of a blocking ridge again this May raises several points of interest. In writing of the weather for May 1954, Klein [1] described a similar blocking regime for that month with an anomaly of +380 ft. in the southern

[1] See Charts I–XV following page 115 for analyzed climatological data for the month.

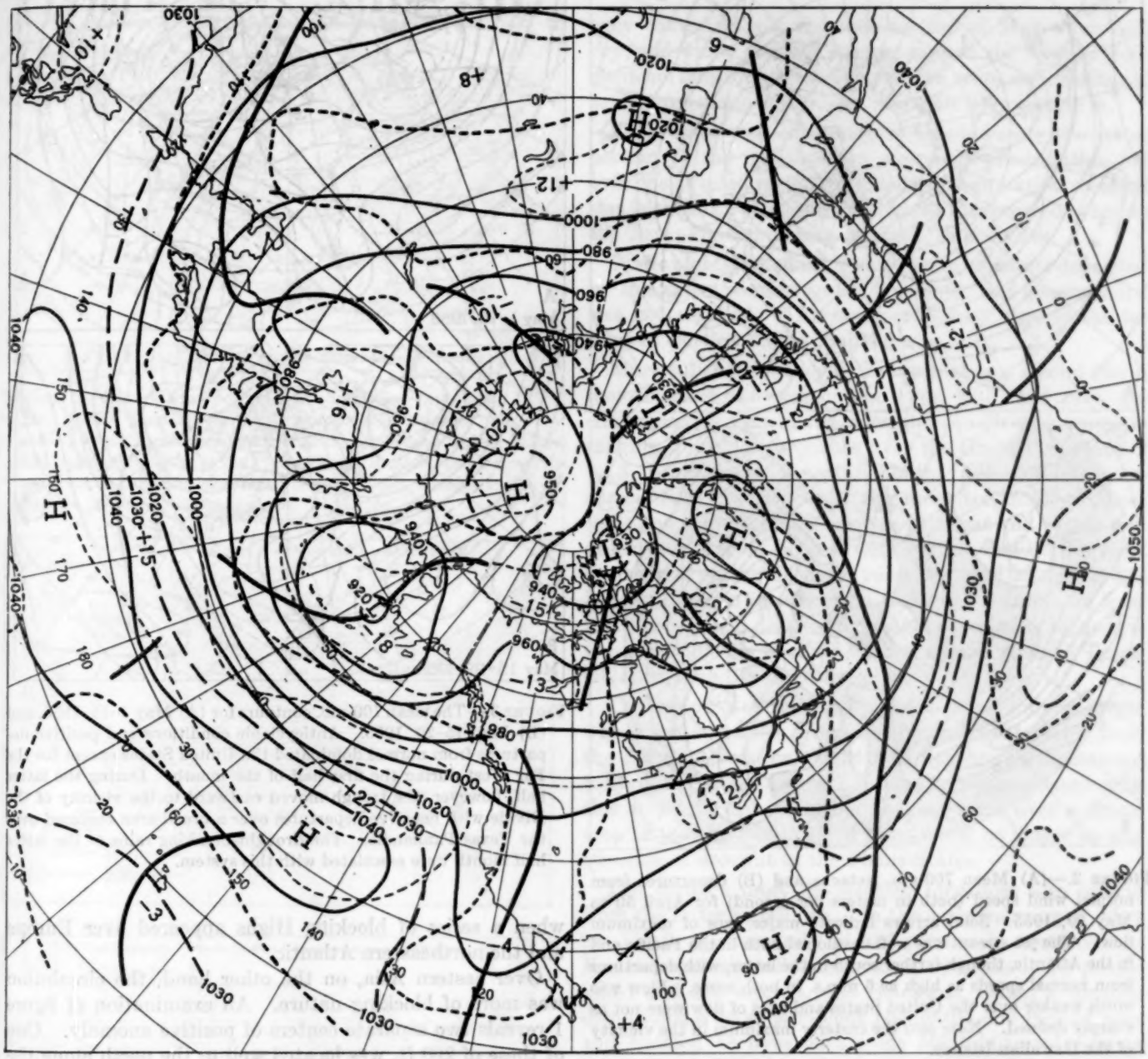

FIGURE 1.—Mean 700-mb. contours and height departures from normal (both in tens of feet) for April 30 to May 29, 1955. The fast Pacific westerlies were associated with repeated thrusts of cool maritime air into the mean trough over the western United States. Colder than normal air again dominated the West while temperatures under the ridge in the East were above normal.

Davis Straits. Also he prepared a composite 700-mb. chart for the previous eight Mays, 1946–1953, and again found that positive departures overspread this area with a central value of 160 ft. The repetition of this feature this May lends additional weight to the implication that either there exists an error in the long period normals used, or the past 10 years represent a secular trend in the general circulation.

The above indicated prevalence of the blocking regime in May is in good agreement with the results obtained by Rex [2] that Atlantic blocking activity for the periods 1933–1940 and 1945–1949 was more characteristic of May than any other month of the year.

An inspection of 5-day mean charts for this period reveals that blocking proceeded westward across the Davis Straits roughly in three waves: one early in the month, a second about mid-month, and the last toward month's end. Of these the second was most pronounced and produced a departure from normal of +660 ft. at the southern tip of Greenland for the 5-day period May 11–15. Twenty degrees due south of this abberation was a center of −590 ft. and the combined effect of the two was a very strong component of anomalous easterly flow.

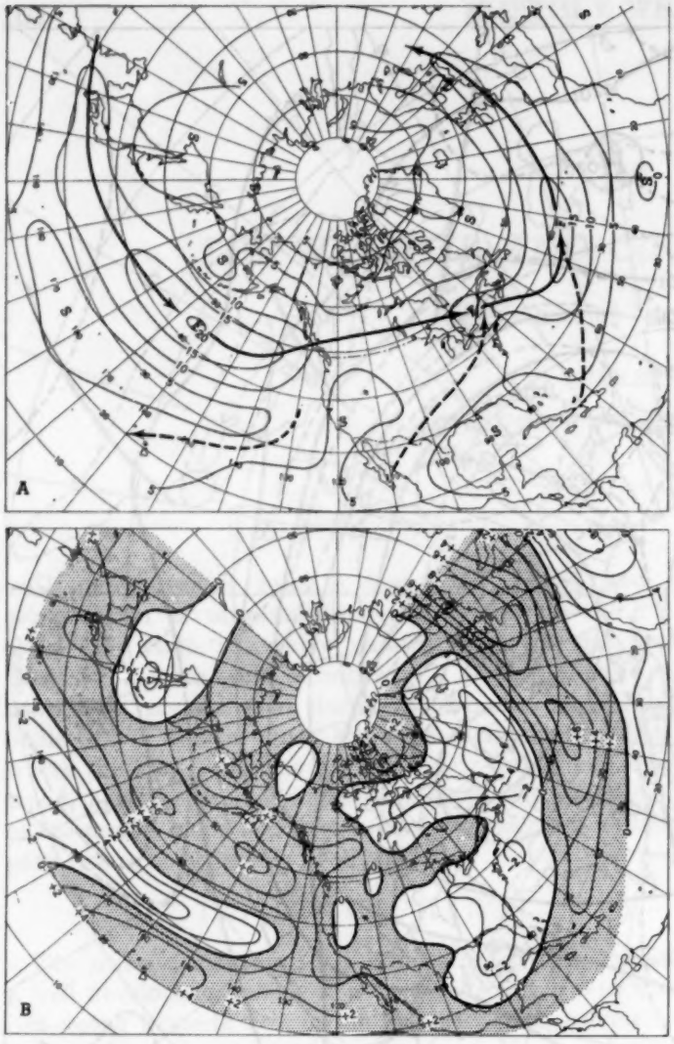

FIGURE 2.—(A) Mean 700-mb. isotachs and (B) departures from normal wind speed (both in meters per second) for April 30 to May 29, 1955. Solid arrows indicate major axes of maximum flow. The jet stream was well developed both in the Pacific and in the Atlantic, though farther south in the latter, with departures from normal speeds as high as 6 m.p.s. in both cases. Flow was much weaker over the United States and axes of flow were not as sharply defined. Note also the easterly maximum in the vicinity of the Hawaiian Islands.

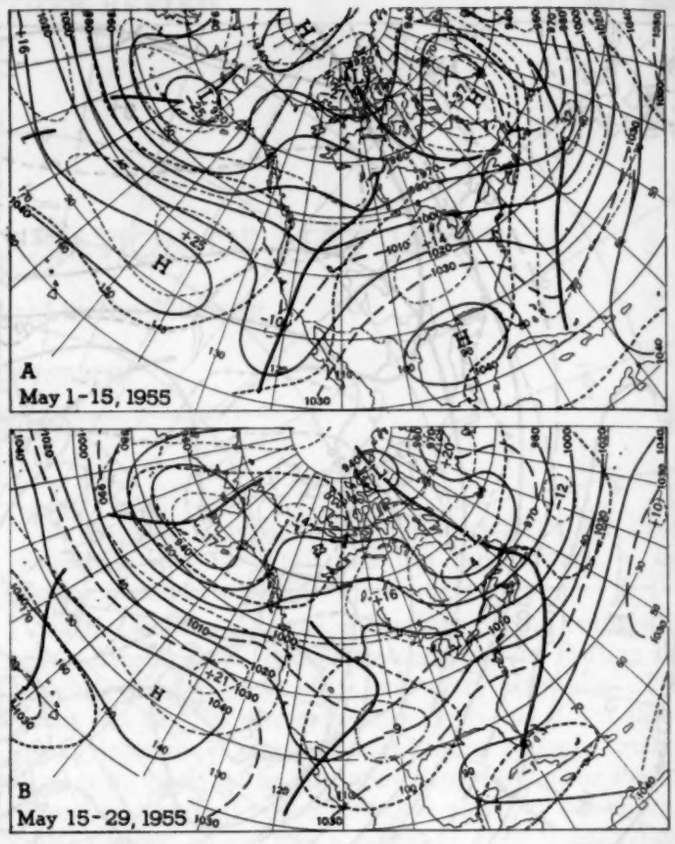

FIGURE 3.—The mean 700-mb. contours for (A) May 1–15, 1955, and (B) May 15–29, 1955. Anticyclonic conditions and positive departures from normal dominated the United States except for the Far West during the first half of the month. During the latter half, however, the trough moved eastward to the vicinity of the Divide with negative departures over a broad area centered over the Texas Panhandle. The drought-breaking rains of the latter half month were associated with this system.

The largest anomaly by far on the mean 700-mb. chart for the month (fig. 1) was the center of −400 ft. associated with the mean trough over Scandinavia. Between this depression and a band of above normal heights over the Mediterranean, the westerly jet stream was unusually well developed. In fact normal wind speeds in that area were exceeded by more than 8 m. p. s. as evidenced by figure 2B. Frequent cyclonic activity was associated with this current particularly during the first two decades of the month when a number of intense storms crossed the British Isles and stagnated in the vicinity of the mean depression over northern Scandinavia. This cold stormy weather was interrupted during the last third of the month when a series of blocking Highs appeared over Europe and the northeastern Atlantic.

Over eastern Asia, on the other hand, the circulation was more of blocking nature. An examination of figure 1 reveals two separate centers of positive anomaly. One of these of 200 ft. was located well to the north along the north Siberian coast, and the other of 160 ft. over northern Sakhalin. Blocking was particularly active the latter portion of the month and reached maximum development during the last week. During this interval heights were well above normal over almost the whole of Asia north of 30° N. with a maximum departure of over 600 ft. in central Siberia.

3. THE DROUGHT

As discussed in the April 1955 article [3] of this series, last month saw a gradual intensification of drought conditions over most of the Plains States. This moisture deficiency had been developing for several months and, as indicated in figure 4, rainfall totals for the 8-month period September 1954–April 1955 were subnormal. This tend-

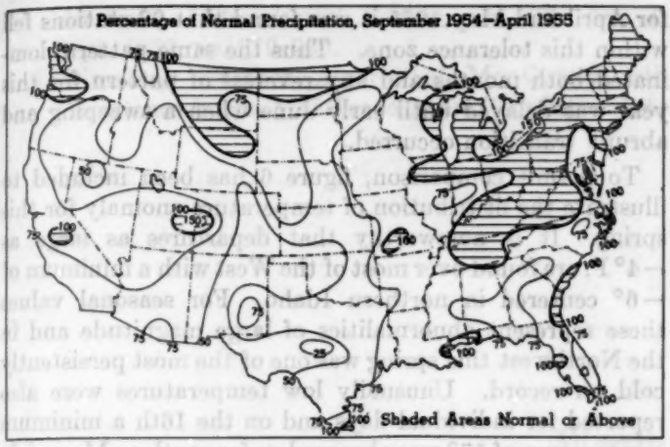

FIGURE 4.—Percentage of normal precipitation, September 1954–April 1955. Rainfall for the 8 months prior to May was subnormal over a broad area of the central and western United States and particularly so over the Plains States, most of which received less than 75 percent of normal. (From *Weekly Weather and Crop Bulletin, National Summary*, vol. XLII, No. 19.)

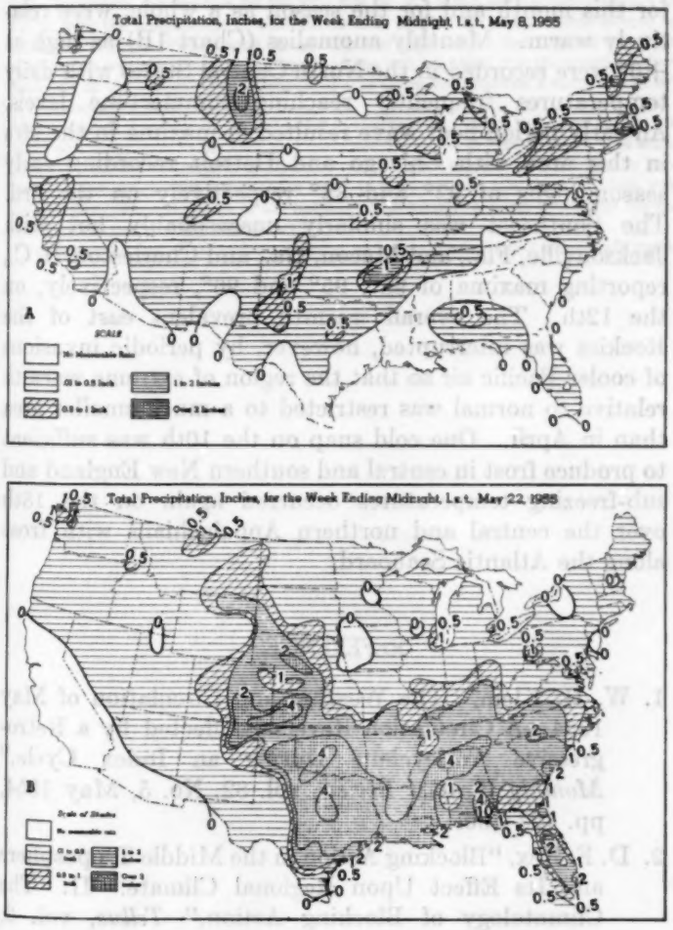
Total Precipitation, Inches, for the Week Ending Midnight, l.s.t., May 8, 1955
A
Total Precipitation, Inches, for the Week Ending Midnight, l.s.t., May 22, 1955
B

FIGURE 5.—Total precipitation in inches for the week ending midnight (A) May 8, 1955, and (B) May 22, 1955. The former is typical of the relatively dry rainfall regime of the first portion of the month and the latter of the wet regime in the central and southern Plains States and in the Southeast in the second half of the month. (From *Weekly Weather and Crop Bulletin, National Summary*, vol. XLII, Nos. 19 and 21.)

ency continued into the first portion of May when hot, dry, and windy weather further sapped the already deficient soil moisture to the point where crops were damaged or destroyed and soil erosion and drift were setting in.

This trend was effectively reversed during the latter portion of the month when abundant precipitation fell over the affected regions. The first precipitation received was in the form of showers as a squall line proceeded across the Texas-Oklahoma area on the 11th and 12th.

While highly beneficial in some areas, amounts deposited by this storm were irregular and spotty and general relief was not afforded. This was particularly true of the far western portion of the Plains States.

More substantial alleviation resulted as a second storm moved across the area on the 17th, 18th, and 19th, accompanied by very heavy rains and squalls with amounts ranging from 1 to 10 inches over the Great Plains and 2 to 3 inches over the entire South. Local flooding occurred in connection with the more torrential of these rains and a considerable acreage of wheat and cotton was destroyed in south-central Oklahoma. One of the most destructive spring floods in years occurred along the Arkansas River in southeastern Colorado, isolating at least 2,000 people and destroying bridges and closing highways. Other flash floods were reported in several areas in Texas, Oklahoma, and New Mexico.

The region was visited by yet a third intense storm whose center passed across the Lower Great Plains from the Far Southwest on the 26th and thence northeastward toward the Great Lakes. A squall line associated with this storm furnished further soaking rains over a broad area so that by month's end there could no longer be any question of drought in the Plains States.

The spring's most devastating tornadoes also sprang from the latter squall line. In the early morning of May 26, Udall, a community of 500 persons in south-central Kansas, was virtually obliterated with about 70 people killed and 200 injured. At Blackwell, Okla., a tornado demolished a 36 square-block residential and factory area and claimed 18 lives with some 500 additional persons injured (see Weather Notes, p. 109). Other tornadoes were reported from Sweetwater, Okla., Oxford, Kans., Jessieville, Ark., and Wathena, Kans., with numerous funnels observed at other locations.

In order to relate the above series of events to the large-scale circulation features, the mean 700-mb. flow pattern (fig. 1) has been divided into two periods. During the first (fig. 3A) the Mississippi Valley was overlain by a ridge at the 700-mb. level with isobars curved anticyclonically over the Plains States. The combined effect of these was to effectively inhibit precipitation. Further, that portion of the flow which represented a departure from the normal was easterly over the Southern Plains with a trajectory such that it had little opportunity to acquire a moisture supply from the Gulf of Mexico. Figure 5A is representative of rainfall distribution during

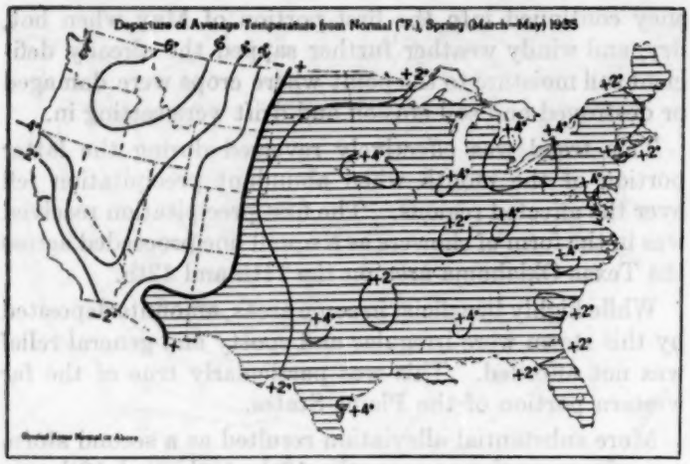

FIGURE 6.—Departure of average temperature from normal (° F.) for the spring season, March–May 1955. This spring was persistently cold in the area west of the Continental Divide with the remainder of the United States warmer than normal. In particular, the anomaly of 6° below normal centered over northern Idaho is an unusually large spring departure. (From *Weekly Weather and Crop Bulletin, National Summary*, vol. XLII, No. 24.)

this period and illustrates the relative dryness of the regime.

Conversely, the air flow during the latter half month had cyclonic curvature over the eastern slopes of the Rockies and the anomalous flow was southerly over East Texas and Louisiana, thus insuring a good moisture supply. Thus the observed pattern as illustrated in figure 5B is explainable in terms of the mean circulation as well as in terms of its individual components.

4. THE TEMPERATURE PATTERN

The most striking aspect of the pattern of temperature anomaly (Chart 1B) was the continuance for the sixth successive month of markedly below normal temperatures in the western third of the country. This month therefore brought to a close an unusually cold winter and spring season in the region west of the Divide. April 1955 was described [3] as one of the coldest on record in the West and the pattern established (cold in the West—warm in the East) persisted strongly into May. That such persistence is not the usual sequence from April to May has been demonstrated by Namias [4 and 5] who found persistence to be a minimum during this period for the decade he studied (ending 1951). In fact, he found a slight tendency to reversal of anomaly pattern from April to May. Klein [1] and Aubert [6] have treated the individual Mays of 1954 and 1950 in which such a reversal ensued. In the light of this tendency the remarkable similarity of thermal pattern between April and May of this year was all the more striking. A convenient statistic for measuring persistence from one month to the next is a simple count of the number of stations out of 100 selected cities which remained in the same or in an adjacent temperature class. When this was computed for April and May 1955 it was found that 98 stations fell within this tolerance zone. Thus the same pattern dominated both months and any reversal of pattern for this year was delayed until early June when a sweeping and abrupt transition occurred.

To permit comparison, figure 6 has been included to illustrate the distribution of temperature anomaly for this spring. It is noteworthy that departures as large as −4° F. are found over most of the West with a minimum of −6° centered in northern Idaho. For seasonal values these represent abnormalities of large magnitude and in the Northwest this spring was one of the most persistently cold on record. Unusually low temperatures were also reported for individual days and on the 16th a minimum temperature of 17° was observed as far south as Maverick, Ariz. Freezing temperatures occurred in the central and northern Rockies and in the Great Basin as late in the season as May 27 and 28, causing some damage to crops and truck gardens.

Contrariwise the eastern two-thirds of the country, both for this month and for the season as a whole, were relatively warm. Monthly anomalies (Chart 1B) as high as +6° were recorded in the North Central States with daily temperatures frequently reaching summertime levels. An early period heat wave resulted in maxima in the 90's in this area with Chicago and Detroit recording early season highs of 92° and 88° respectively on the 3rd. The Southeast was similarly unseasonably hot with Jacksonville, Fla., and Macon, Ga., and Charleston, S. C., reporting maxima of 98°, 95° and 96°, respectively, on the 12th. The overall warmth prevalent east of the Rockies was interrupted, however, by periodic invasions of cooler Pacific air so that the region of extreme warmth relative to normal was restricted to a much smaller area than in April. One cold snap on the 10th was sufficient to produce frost in central and southern New England and sub-freezing temperatures occurred again on the 18th over the central and northern Appalachians with frost along the Atlantic Seaboard.

REFERENCES

1. W. H. Klein, "The Weather and Circulation of May 1954—A Circulation Reversal Effected by a Retrogressive Anticyclone During an Index Cycle," *Monthly Weather Review*, vol. 82, No. 5, May 1954, pp. 123–130.
2. D. F. Rex, "Blocking Action in the Middle Troposphere and Its Effect Upon Regional Climate. II. The Climatology of Blocking Action," *Tellus*, vol. 2, No. 4, Nov. 1950, pp. 275–301.
3. A. F. Krueger, "The Weather and Circulation of April 1955—Another Cold Month in the West," *Monthly Weather Review*, vol. 83, No. 4, April 1955, pp. 95–97.
4. J. Namias, "The Annual Course of Month-to-Month Persistence in Climatic Anomalies," *Bulletin of the*

American Meteorological Society, vol. 33, No. 7, Sept. 1952, pp. 279–285.

5. J. Namias, "Further Aspects of Month-to-Month Persistence in the Mid-Troposphere," *Bulletin of the American Meteorological Society*, vol. 35, No. 3, March 1954, pp. 112–117.

6. E. J. Aubert, "The Weather and Circulation of May 1950," *Monthly Weather Review*, vol. 78, No. 5, May 1950, pp. 81–83.

Weather Notes

TORNADOES AT BLACKWELL, OKLA., MAY 25, 1955

On Wednesday, May 25, the wind was east-southeast all day. At approximately 4 p. m. the barometer started to fall from 30.05 inches. By 9:00 p. m. the barometer was steady at 29.64 and started to rise. The clouds that were approaching from the west were not bad looking at all. When the storm hit Blackwell (at 9:27 p. m.) my barometer was reading 29.72 and by 4 p.m. on the 26th it was back to 30.00.

The maximum temperature for the 25th was 78° F. I had set the thermometers at 7 p. m. with the temperature at observation time reading 74° as the clouds seemed to gather in the west. The temperature remained at 74° until the storm struck and went to 80° which was also the 24-hr. maximum on the 26th. I noted that the recording thermometers at the Journal and Consolidated Gas Office both showed a sharp rise to 80° at the time of the storm, 9:27 p.m.

Hailstones that measured 2¼ inches fell in my yard just before the storm struck. A friend picked up some in his yard that measured 2½ inches in diameter on a steel scale. Jumping from the north porch of his house into the yard to pick up hailstones, he happened to look around the corner of the house to the south and saw the solid black wall approaching. He took refuge in the hallway of his house. He and two others tell me that they did not hear any noise at all.

One lady who took cover under a stairway ended up one-half block away—still under the stairway, which was all that was left of her two-story house. She tells me the storm was a black wall and the lightning went up from the ground to the cloud—not from the cloud to the ground.

I stood in the door of my storm cellar and watched the storm go through town. The wind at my place, nine blocks west of the main path, was a dead calm. The storm sounded like a roaring freight train going through open country, only louder. As the funnel was directly east of me, the fire up near the top of the funnel looked like a child's Fourth of July pin wheel. It was something I will not forget for a long time.

I walked out to my back fence after the main storm passed and was listening to the noise die away when all at once the noise came back clearly. I ran back to the cave and said, "It's coming back." Then I looked again and there was a smaller one in the air about one-half mile behind the first one. It came down North First which is about six blocks east of my home, and about five blocks west of the main storm path.

Two miles south of Tonkawa along the Salt Fork River there was evidence of the storm starting at the mouth of the Chikaskia and Salt Fork. On the west side of the Chikaskia it started north along the river and got bigger as it went.

This is the fourth storm I have been through here at Blackwell. Always before they have come in from the west, cut a path, hit the river and broken up.—

Floyd C. Montgomery, Observer, Blackwell 2, Okla.

THE DEEPENING CYCLONE IN THE NORTHERN PLAINS STATES, MAY 1–4, 1955

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1. INTRODUCTION

On May 4, 1955, there was a surface Low with central pressure slightly below 980 mb. just north of Minot, N. Dak. (fig. 3). As far as May storms are concerned, this one was not of particularly unusual dimensions nor was the weather which accompanied it of spectacular significance, although the cold front which trailed back into central Texas did trigger a few tornadoes in Wisconsin and locally severe storms in Iowa [1]. Along with the intensification of this storm, a surge of warm air caused temperatures to the east of the storm to rise to the high 80's and low 90's as far north as Detroit, Mich.

The purpose of this report is to present a descriptive case study of this deepening storm, highlighting those aspects which the day-to-day forecaster has time to consider before making his prognosis of the situation. The National Weather Analysis Center (NWAC) prognostic charts for the period involved are presented (fig. 1), the synoptic sequence, surface and aloft, is discussed, and a few upper air aspects of this deepening storm are examined.

2. THE PROGNOSIS

The NWAC 30-hour surface prognostic chart which verified at 0030 GMT, May 4, and the accompanying 36-hour 500-mb. prognosis which verified at 0300 GMT, May 4, are shown in figure 1. A comparison of these two prognoses with the observed charts (fig. 3) shows that little of the storm's development was forecast. This is borne out by comparison of the verification scores for these charts with the scores for all others made during May (assuming all forecast situations were of equal difficulty). According to the NWAC verification system [2] in which the lower score is the better prognosis, the surface prognosis scored 83 compared with a May average of 63, incidentally, the best month of record in 8 years of verification. The 500-mb. prognosis scored[1] 72 with a May average of 55.

Even in retrospect it is not always a small job to determine why any given forecast failed. But the discussion in the sections which follow may serve to convince the reader that this was a difficult forecast to make. In presenting these NWAC prognoses it is the authors' intent merely to emphasize that there is some utility even in a poor prognosis. The detailed study of these prognoses and the further evaluation and examination of this forecast problem beyond that which follows are left to the reader.

[1] The 500-mb. verification system used by NWAC is based on gradient comparison similar to that used for the surface but in which it is assumed that the forecasting of west-east gradients is twice as difficult as forecasting the south-north gradients.

3. SYNOPTIC SEQUENCE AT THE SURFACE

At 0030 GMT, May 1, a weak, complex Low (with centers and fronts shown on figure 4) covered the United States from the Great Plains westward. A 1026-mb. High was centered north of Fort Wayne, Ind., with a moderate ridge extending from the Yucatan Peninsula to the Great Lakes, thence to Resolute, Northwest Territories. This ridge constituted a temporary blocking condition which was further indicated by a +1200-ft. 1000-500-mb thickness departure from normal centered between Lake Winnipeg and Lake Superior. Before breaking down, this block was effective in keeping low pressure systems confined principally to the western portions of North America.

By 1230 GMT, May 2 (fig. 2), the western half of the United States was still predominantly under the influence

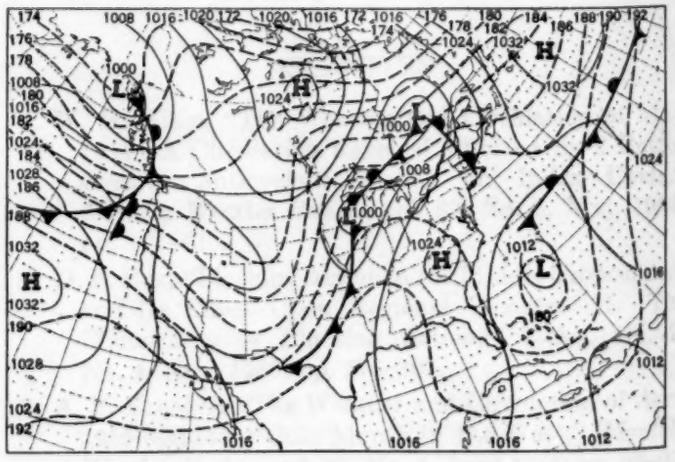


FIGURE 1.—30-hr. prognostic surface isobars (solid lines) with positions of fronts and centers for 0030 GMT, May 4, 1955; and 36-hr. prognostic 500-mb. contours (dashed lines) for 0300 GMT, May 4, 1955.

of low pressure with a 998-mb. center near Cheyenne, Wyo., showing signs of becoming better organized than it had been, as the block over Canada gave way rapidly. The northern portion of the ridge moved eastward and extended from New England to Yucatan. Little significant weather was evident. Fairly steady precipitation over central and southern California, less than one-half inch for the most part, had just about ceased. Meanwhile, continuous light rain had begun to fall over western Montana.

The surface pressure tendencies at that time were not at all indicative of the deepening about to occur. On the 1230 GMT surface chart for May 2 (fig. 2) there were few 3-hr. tendencies, within 500 miles of the center, which exceeded 1-mb. fall or rise. (Diurnal variations of pressure over the Northern Plains States are negligible at 1230 GMT.)

Thirty-six hours later (fig. 3) the maximum deepening had taken place over North Dakota. As the storm developed into a major depression, the effects of the rapid deepening were noted in all directions. The ridge over the eastern United States continued to rotate clockwise around a more or less stationary pivot in the Gulf of Mexico. Warm air flooded the western Great Lakes area as air some 40° to 50° F. colder flowed from Canada into the extreme northern part of North Dakota. (A few days later temperatures dropped below freezing in the upper Mississippi Valley and Great Lakes area as the storm sped to the northeast and was replaced by a cold Canadian High.) Except for the local storms noted in the Introduction, winds at the surface seldom exceeded 40 m.p.h. Rainfall totals in eastern Montana were generally from one-half to 1 inch, ranging to a maximum of 2.44 in. at Miles City [1]. In North Dakota smaller amounts, in most cases not exceeding one-half inch, were measured.

The pressure at 2130 GMT, May 4, was 979.9 mb. at Minot, N. Dak. Pressure rises of 5 to 8 mb. per 3 hr. occurred in North Dakota as the Low moved into the province of Manitoba.

4. SYNOPTIC SEQUENCE AT THE 500-MB. LEVEL

A summation of the long-wave features beginning 72 hours before 0300 GMT, May 4, follows: At 0300 GMT, May 1, there were long-wave troughs located at longitudes 70° W. 120° W., and 160° E. Midway between the two westernmost troughs there was a fastmoving short-wave trough. After 36 hours (fig. 2) there was relatively little change in the general features of the long-wave pattern. The amplitude of the troughs was not appreciable except over North America where the amplitude was between 1200 and 1500 miles. Because the wave lengths of the long waves were not too well adjusted for a stationary state, it now seems fairly obvious that the short-wave trough which moved into the Gulf of Alaska was of very considerable importance in readjusting the mean and immediate picture. At the time of prognosis its importance was either unrecognized or underestimated. By 0300 GMT, May 4 (fig. 3), the long waves were of roughly stationary length with their axes along longitudes 70° W., 130° W., and 175° E. During this readjustment the short-wave impulse which moved into the Gulf of Alaska forced warm air into western North America as the cold air associated with it pushed southward. The result was an acceleration of the short-wave trough out of the long-wave trough and into the Great Plains States, and a retrograde motion of the long-wave trough in the west.

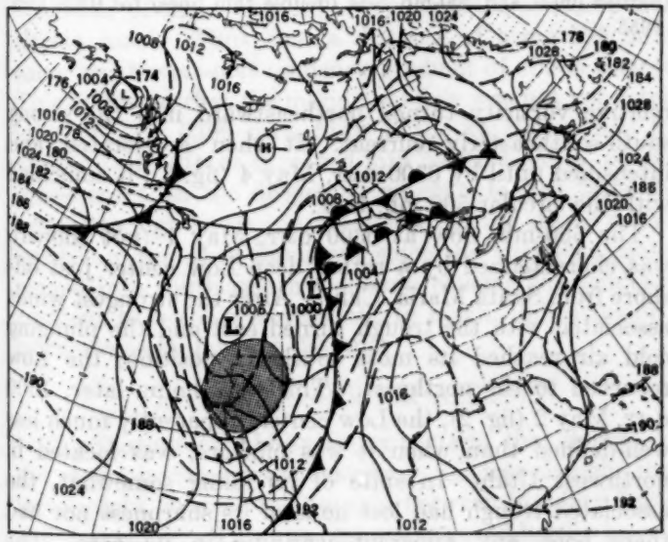


FIGURE 2.—Surface isobars (solid lines labeled in millibars) for 1230 GMT, May 2, 1955; and 500-mb. contours (dashed lines labeled in hundreds of geopotential feet) for 1500 GMT, May 2, 1955. Stippling represents principal region of cyclonic relative vorticity.

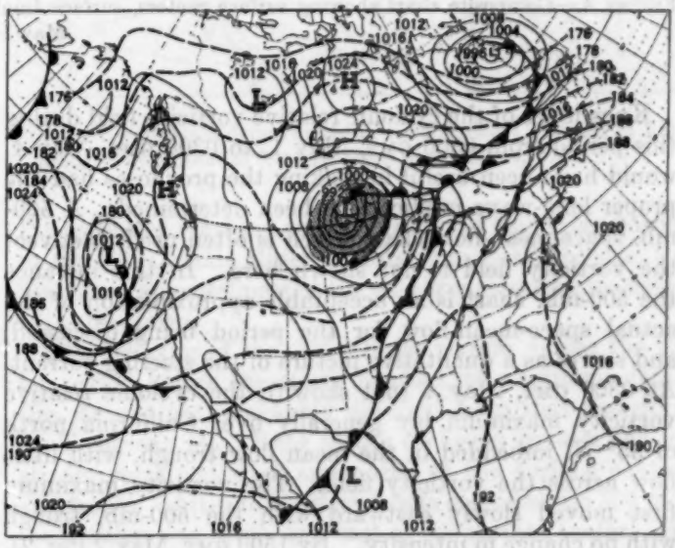


FIGURE 3.—Surface isobars (solid lines labeled in millibars) for 0300 GMT, May 4, 1955; and 500-mb. contours (dashed lines labeled in hundreds of geopotential feet) for 0300 GMT, May 4, 1955. Stippling represents principal region of cyclonic relative vorticity.

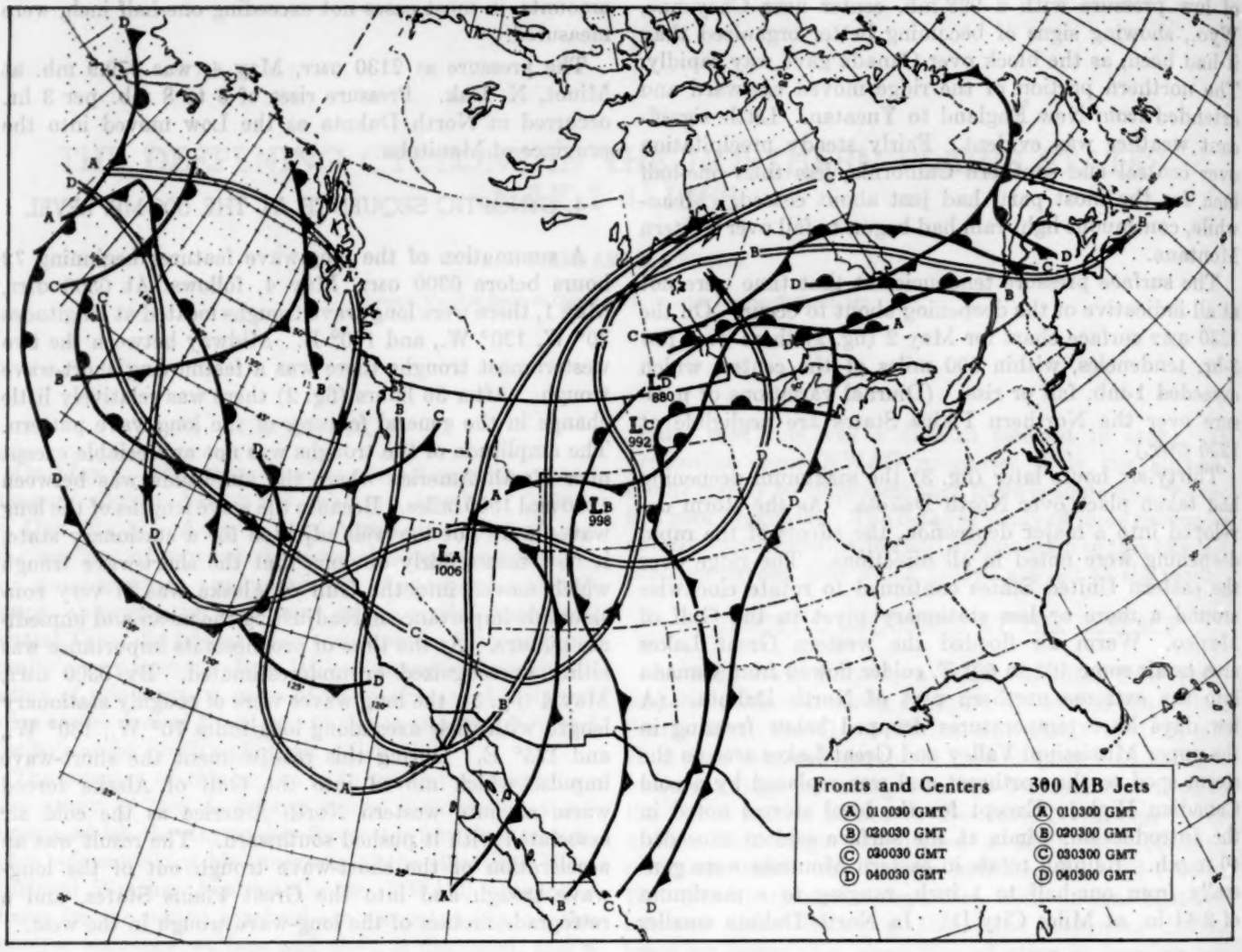


FIGURE 4.—Composite chart showing surface centers, surface fronts (barbed lines) and 300-mb. jets (double thin lines) for 0300 GMT. May 1–4, 1955.

Knowledge of the cyclonic relative vorticity field during this period from 0300 GMT, May 1, to 0300 GMT, May 4, would have been useful in making the prognoses had the proper long-wave implications been determined. A 500-mb. space-mean-flow chart which is often used to advect the vorticity field is not shown here. In this instance the 500-mb. chart is an acceptable approximation of the actual space-mean-flow for the period being discussed, and serves as a qualitative picture of the steering current. At 0300 GMT, May 1 (not shown), the cyclonic relative vorticity maximum lay generally over California north of 35° N. imbedded in the mean flow trough, with little flow across the vorticity field. The vorticity maximum first moved slowly eastward with the 500-mb. trough with no change in intensity. By 1500 GMT, May 2 (fig. 2), the vorticity maximum lay over Arizona and was approaching a region of strong 500-mb. (mean flow) contour gradient. Shortly thereafter the maximum of cyclonic relative vorticity turned northeastward into the strong south-southeasterly current. It then accelerated and intensified until by 0300 GMT, May 4 (fig. 3), it coincided with the circular 500-mb. Low.

The 500-mb. flow at 0300 GMT, May 1 (not shown), was characterized by a rather deep Low center just offshore from Santa Maria, Calif. After the strongest winds associated with the trough turned east and the plunging cold air reached its most southerly position, the Low recurved to the northeast. Thirty-six hours later, 1500 GMT, May 2 (fig. 2), the Low center, apparently much less well-defined than when it was offshore, was located in northwest Utah. In spite of its filling somewhat, the associated trough had lost none of its sharpness nor had there been any apparent warming in its core. The weakening ridge to the east still maintained some of its blocking characteristics, but showed further signs of weakening north of 50° N. as height falls ate into its

northern perimeter. Isobars and isotherms were still essentially in phase, but with some hint of cold air advection beginning to appear in the southern and central Rocky Mountain area. By 0300 GMT, May 4 (fig. 3), the 500-mb. center had deepened approximately 400 ft. and showed a gradually accelerating northeastward movement. It then lay over the Manitoba–North Dakota border, not quite vertical with the surface center.

The 500-mb. departure from normal chart (fig. 5) for 36 hours before the surface and 500-mb. deepening, indicates a 200-600 ft. positive departure from normal which extended from Baffin Island to the Southern Plains States. A negative departure of equivalent magnitude was centered near Las Vegas, Nev. Another 600-ft. negative departure from normal in the Gulf of Alaska reflected the new short-wave trough moving from the northwest into the old long-wave position. It must have been apparent at the time the prognoses were made that this short wave would cause the cold air over Las Vegas to accelerate to the northeast. (Therein lies perhaps the basic error in the forecasts: the long-wave trough was taken eastward bodily, instead of bringing in a fast-moving short wave.) In 36 hours (fig. 6) the 500-mb. negative departure had raced north-northeast to North Dakota while the Gulf of Alaska cold pool plunged southward to reinforce the former long-wave trough. The trough associated with the deepening storm had definitely acquired short-wave dimensions and characteristics. The long-wave trough became readjusted to a mean position somewhat farther west than it had been.

Another aspect of the 500-mb. level is that of the 24-hr. height changes (not shown here). Thirty-six hours before 0300 GMT, May 4, there was a moderate katallobar of about 400 ft. over southeastern Colorado. There was an anallobar of more than 400 ft. just off the southern California coast. Thus over a distance of some 600 miles there was a west-east tendency gradient of about 1000 ft. This indicated that the meridional flow was not yet deteriorating. By 0300 GMT, May 4, the katallobar had increased to 800 ft. as it moved into North Dakota, not inconsistent with the deepening which extended from the surface to high levels. A breakdown of the strong meridional flow was then imminent since the anallobar center moved into southeastern Colorado causing the tendency gradient to become more south to north, indicative of a more westerly flow at 500-mb.

5. OTHER UPPER AIR ASPECTS

The Showalter Stability Index patterns (not shown) for the period involved were examined. It was thought that there might be some relationship between Stability Index and deepening. This one case study could hardly be representative in any event, but it is of interest to note that there were no indications of excessive instability, before the onset of deepening, which could be conclusively correlated with deepening. During the 48 hours preceding intensification there was an area of instability over the

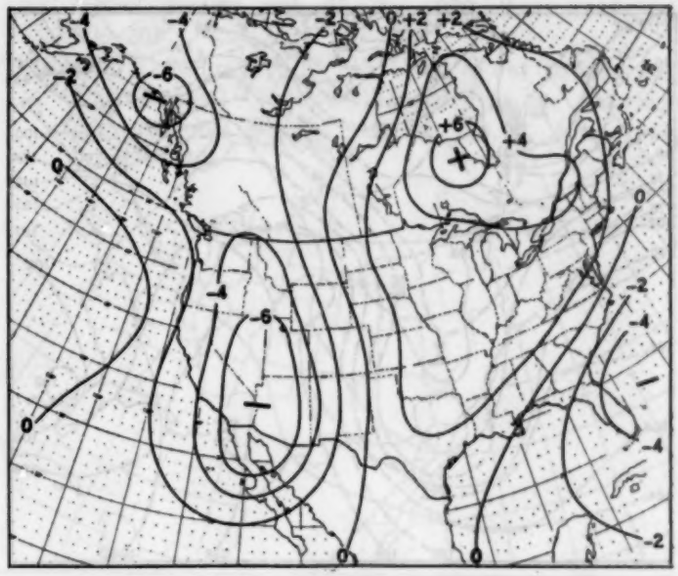


FIGURE 5.—500-mb. departure from normal chart (labeled in hundreds of geopotential feet) for 1500 GMT, May 2, 1955.

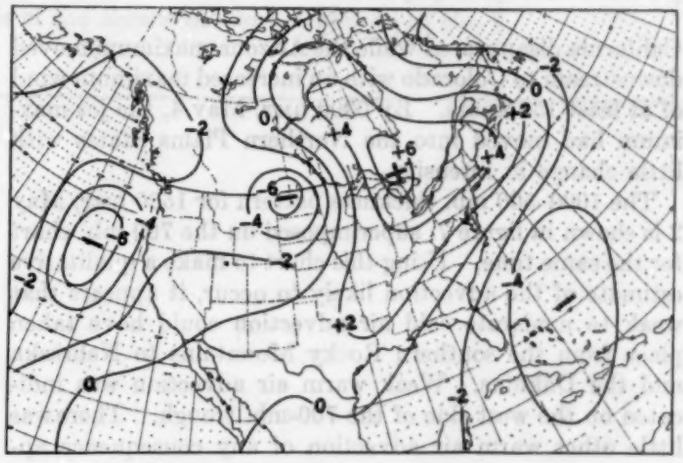


FIGURE 6.—500-mb. departure from normal chart (labeled in hundreds of geopotential feet) for 0300 GMT, May 4, 1955.

Plains States reaching roughly from the Canadian border to the Rio Grande River. More than anything else, the Stability Index delineated the cold frontal zone associated with this storm.

The behavior of the 300-mb. jet stream during the 72-hr. period before the storm reached its maximum depth (fig. 4) was not noticeably different from that described by Vederman [4]. Prior to the occlusion process the jet stream remained west and north of the surface centers and fronts. After the surface fronts occluded the 300 mb. jet position was south and east of the surface center. At 0300 GMT, May 2, the 300-mb. jet stream (fig. 4) was horseshoe shaped over the States west of 110° W. with a maximum speed in excess of 100 knots over central California and another maximum of the same speed over central Arizona. In 24 hours the jet maximum which had been in

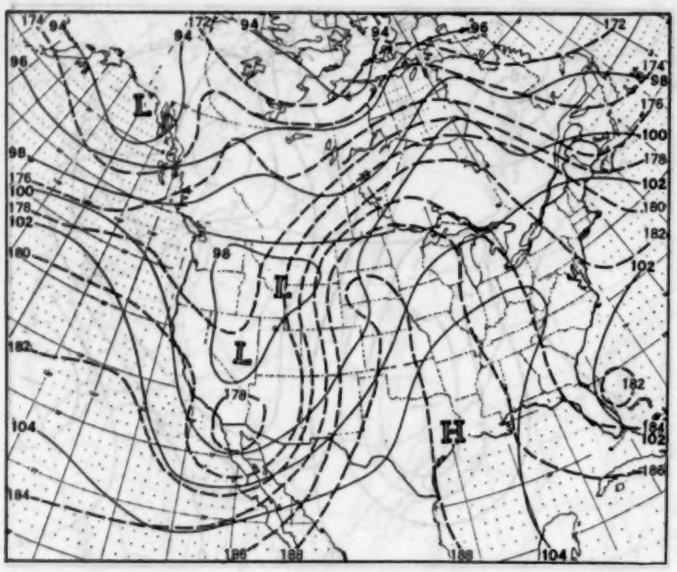


FIGURE 7.—700-mb. contours (solid lines labeled in hundreds of geopotential feet) for 1500 GMT, May 2, 1955; and 1000–500-mb. thickness contours (dashed lines labeled in hundreds of geopotential feet) for 1500 GMT, May 2, 1955.

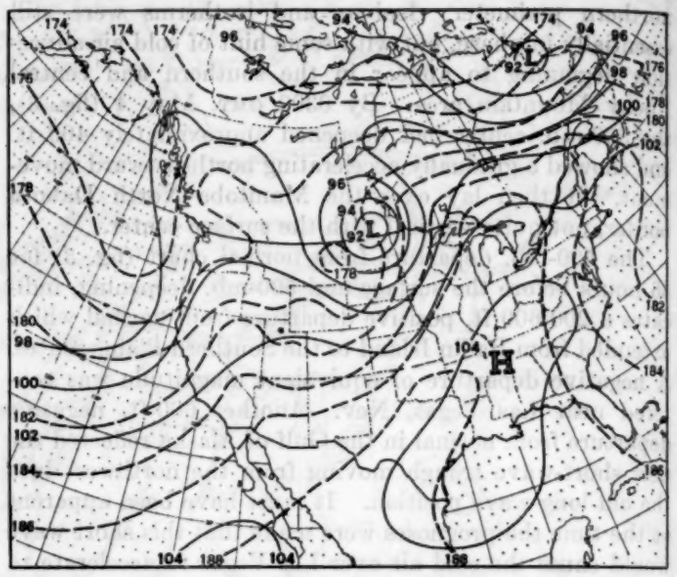


FIGURE 8.—700-mb. contours (solid lines labeled in hundreds of geopotential feet) for 0300 GMT, May 4, 1955; and 1000–500-mb. thickness contours (dashed lines labeled in hundreds of geopotential feet) for 0300 GMT, May 4, 1955.

California disappeared while the Arizona maximum moved downstream to Colorado with an increased maximum wind of at least 150 knots. By 0300 GMT, May 4, the jet maximum had moved into the Northern Plains States with little change in intensity.

The 1000–500 mb. thickness pattern for 1500 GMT, May 2 is shown in figure 7, superimposed on the 700-mb. chart for the same time. Using this chart to make a qualitative estimate of the advection likely to occur, it appears that weak to moderate cold air advection could have taken place from the southern Rocky Mountains to Nebraska and the Dakotas. Weak warm air advection was indicated on the west side of the 700-mb. trough. There was little other warm air advection of any consequence apparent in connection with this storm except far to the east between International Falls, Minn., and James Bay. Therefore, from considerations of advection alone, it was unlikely that deepening would occur. In addition to no apparent warm advection, thickness values in advance of this system were already more than 600 ft. above normal. The configuration of thickness contours did approach one of the deepening models proposed by Sutcliffe and Forsdyke [3]. In figure 7 the thickness contours are generally S shaped from Hudson Bay to the cold pocket over Yuma, Ariz. It takes little imagination to modify this picture into one of the cyclonic thermal involution types. Cyclogenesis would then be expected to proceed near the inflection on the west side of the thermal ridge portion of the involution. An examination of the thickness chart for 0300 GMT, May 4 (fig. 8) shows that thickness values which had been 1000 ft. below normal over California and Arizona were rapidly modified so that by the time of rapid deepening those thicknesses were only 200 ft. below normal with a negative departure from normal of some 500 ft. over northern Wyoming.

In summation, the 1000–500-mb. thickness change during the period prior to 0300 GMT, May 4, amounted to a decrease of approximately 400 ft. in North Dakota. This alone would have caused a rise of 16 mb. at the surface, assuming no change at the 500-mb. level. However, there was a fall of about 800 ft. at 500 mb., 400 ft. of which was canceled out by the 1000–500-mb. thickness decrease. There remained then about 400 ft. of falls at the 500-mb. level which was responsible for a 16-mb. fall at the surface.

6. CONCLUSION

It was the purpose of this study to examine a few general aspects of this deepening May storm and to try to throw some light on those phases which were poorly forecast. Ex post facto arguments have fairly obvious shortcomings, but it is felt that such arguments are worthwhile as long as they are used in trying to gain a better understanding of the forecast situation instead of retrospectively in trying to show how the prognoses should have been made. If only one crisp comment on the prognoses were allowed, the authors would be compelled to state that the long-wave features and modifications thereof had been underestimated.

REFERENCES

1. U. S. Weather Bureau, *Weekly Weather and Crop Bulletin, National Summary*, vol. XLII, No. 19, Washington, D. C., May 9, 1955.

2. Sidney Teweles, Jr. and Hermann B. Wobus, "Verification of Prognostic Charts," *Bulletin American Meteorological Society*, vol. 35, No. 10, Dec. 1954, pp. 455–463.
3. R. C. Sutcliffe and A. G. Forsdyke, "The Theory and Use of Upper-Air Thickness Patterns in Forecasting," *Quarterly Journal of the Royal Meteorological Society*, vol. 76, No. 328, Apr. 1950, pp. 205–208.
4. Joseph Vederman, "The Life Cycle of Jet Streams and Extratropical Cyclones," *Bulletin of the American Meteorological Society*, vol. 35, No. 6, June 1954, pp. 239–244.

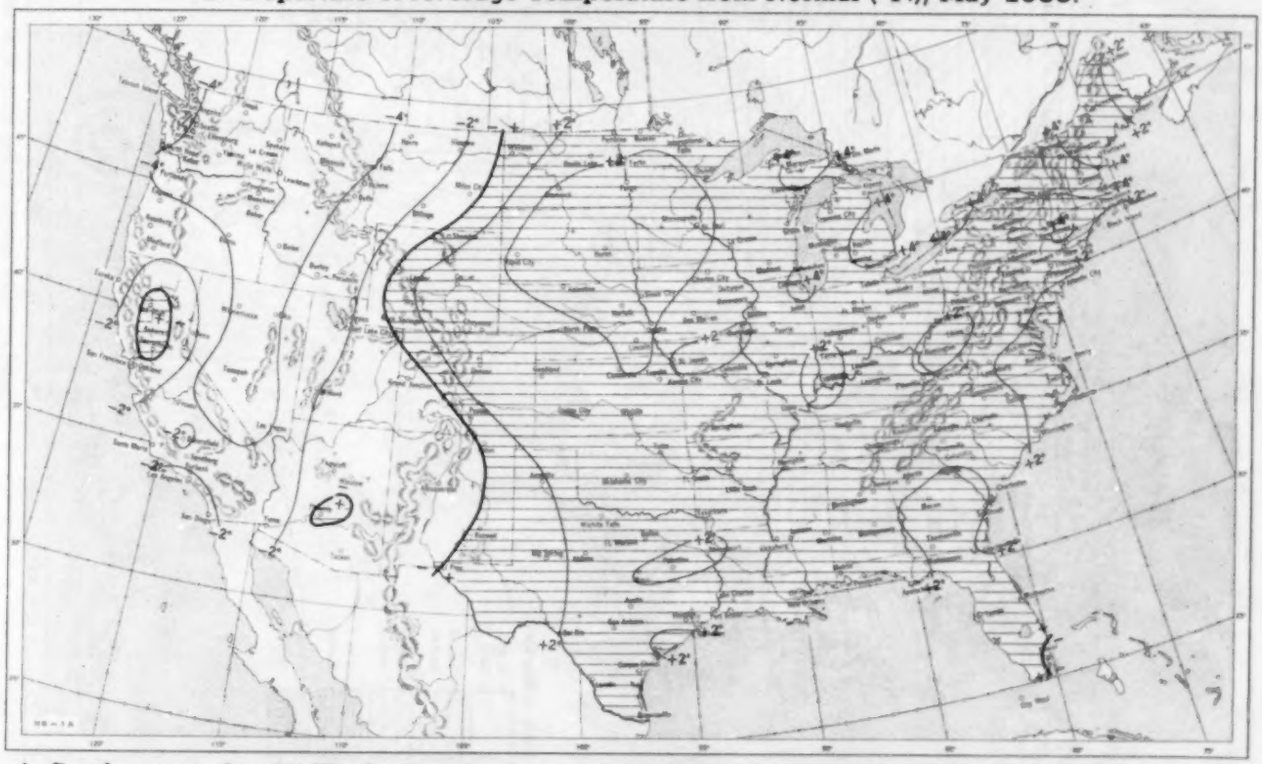
CORRECTION

MONTHLY WEATHER REVIEW, vol. 83, No. 4, page 94: In reference 14 to the paper by Newstein, the number and month of issue of the *Review* should be changed to No. 9, Sept. 1954.

U. S. GOVERNMENT PRINTING OFFICE: 1955

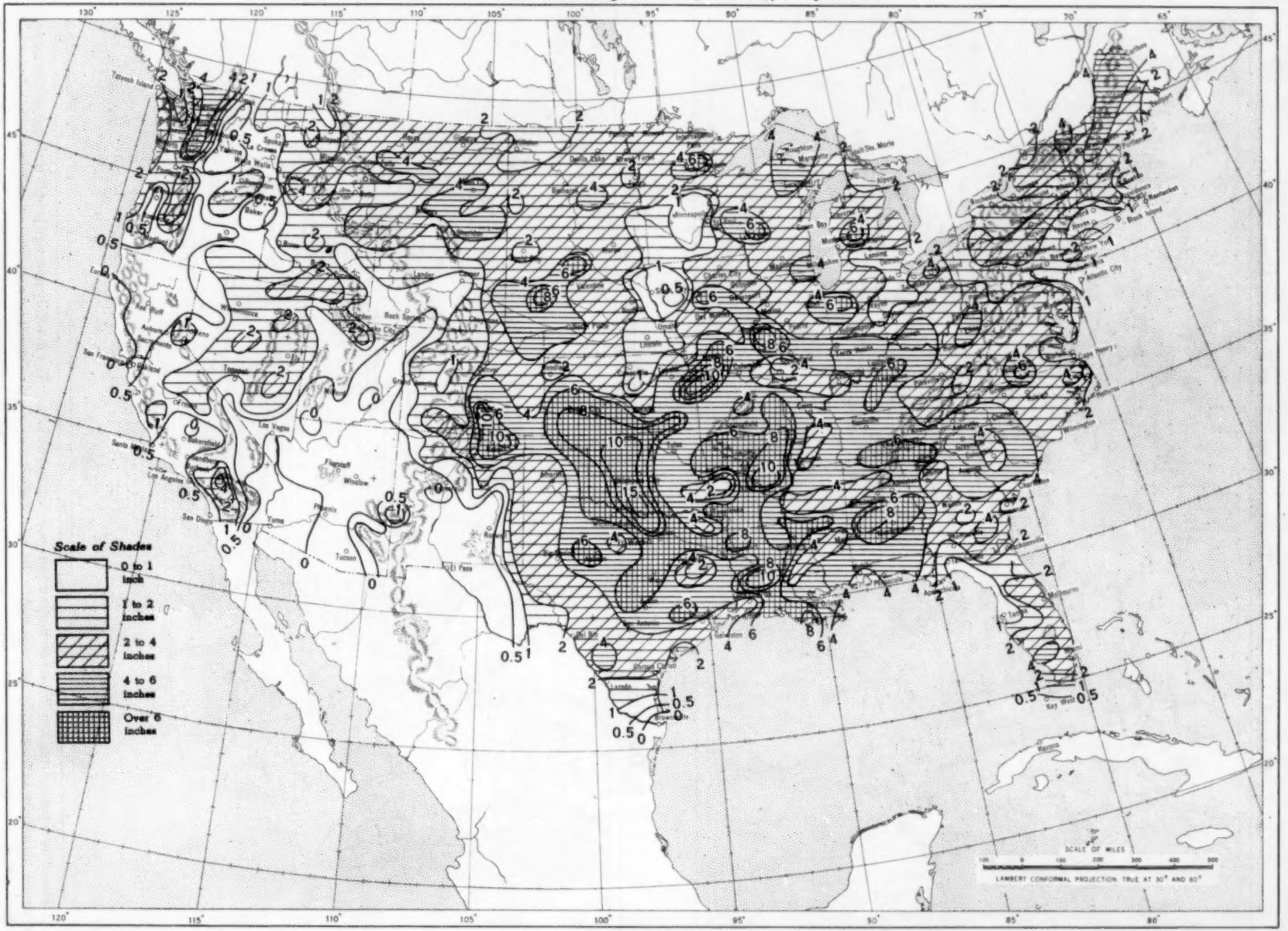
Chart I. A. Average Temperature (°F.) at Surface, May 1955.

B. Departure of Average Temperature from Normal (°F.), May 1955.



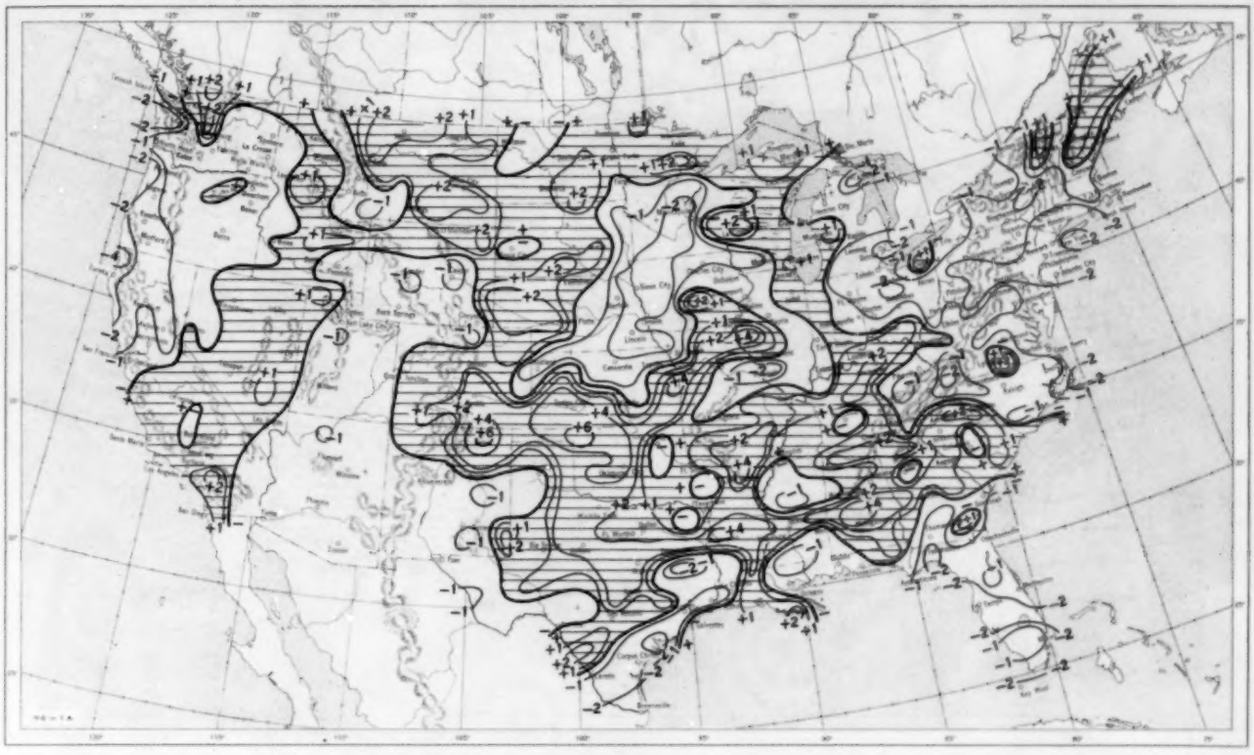
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), May 1955.

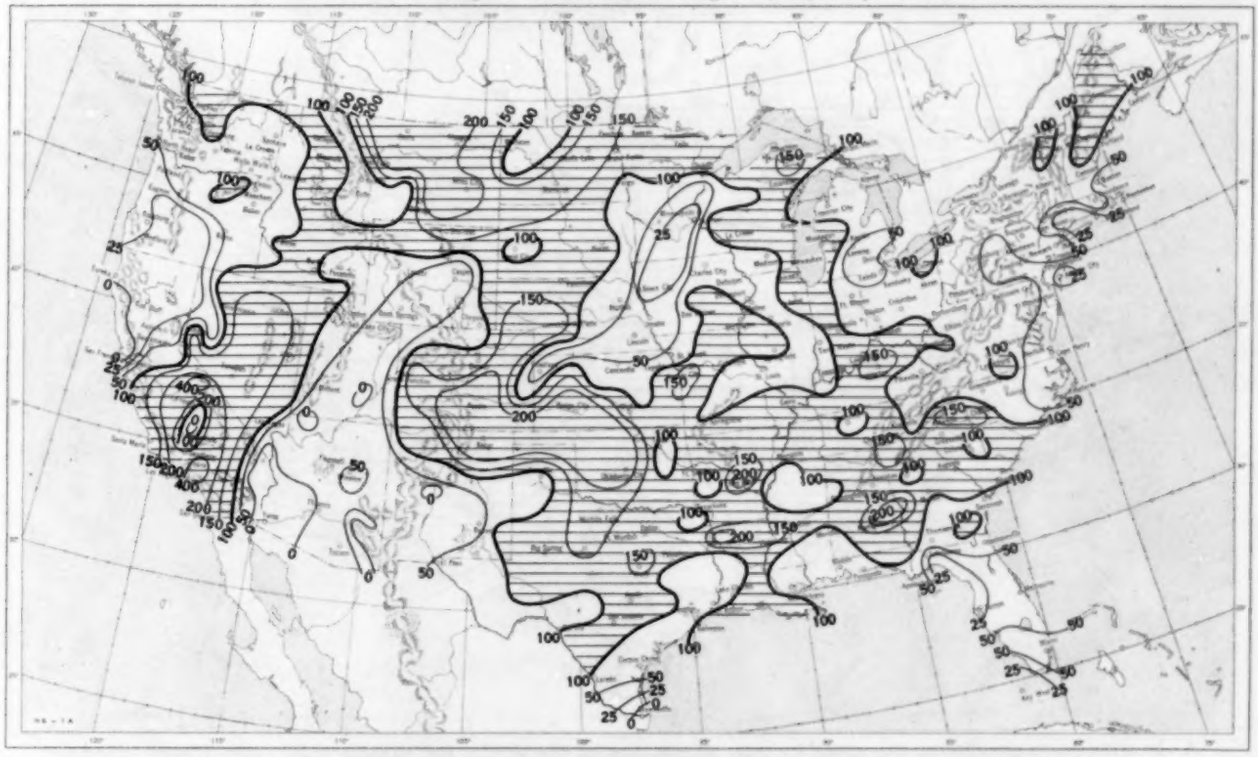

Scale of Shades
0 to 1 inch
1 to 2 inches
2 to 4 inches
4 to 6 inches
Over 6 inches
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION TRUE AT 30° AND 60°

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), May 1955.

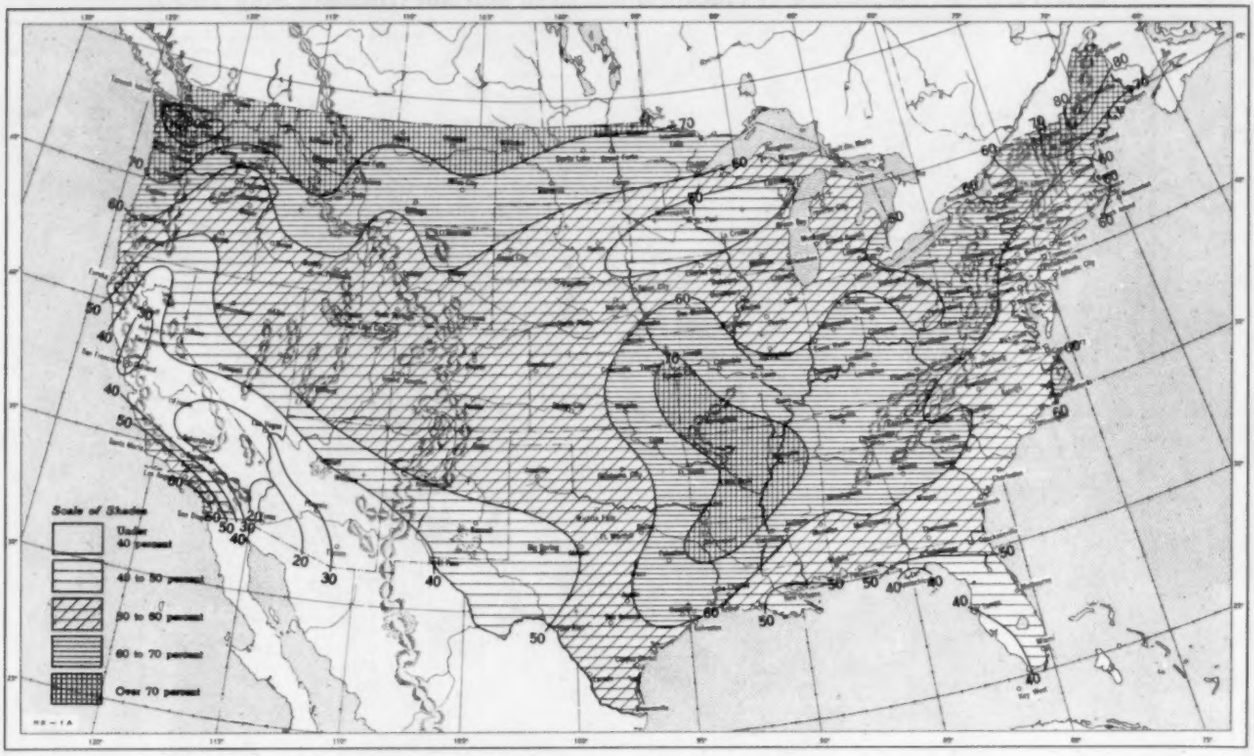


B. Percentage of Normal Precipitation, May 1955.

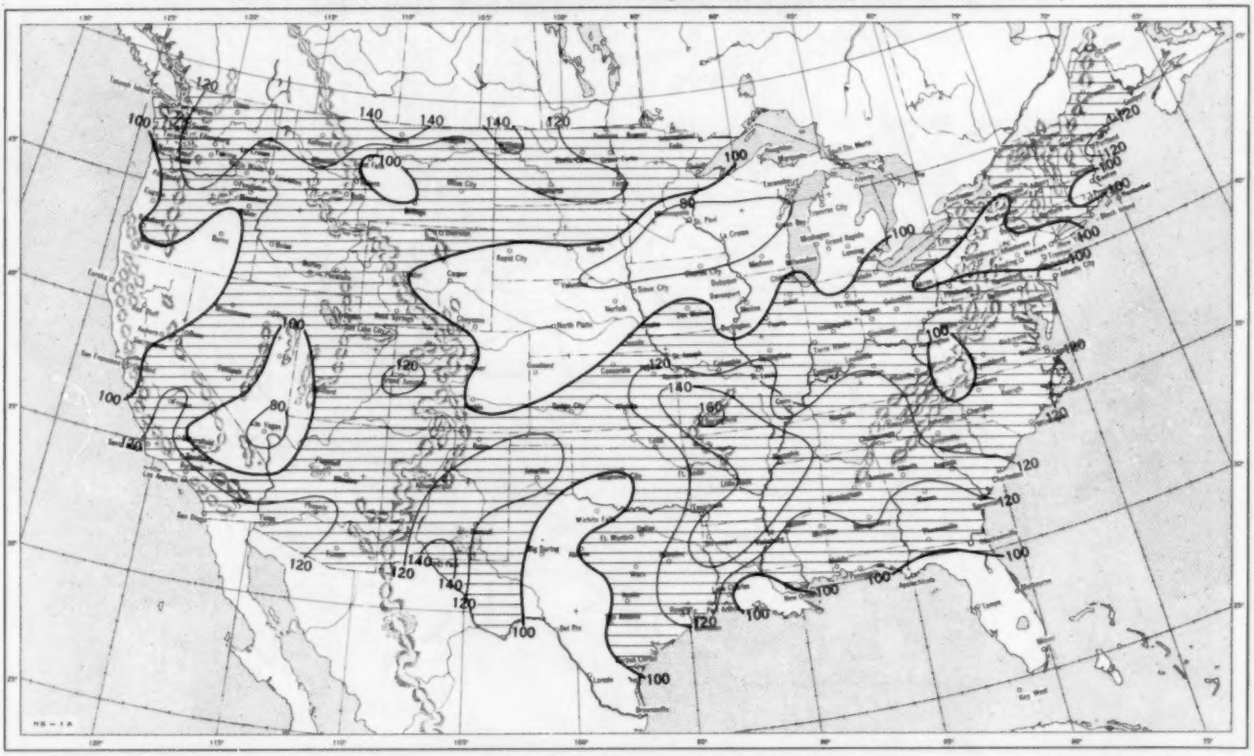


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, May 1955.

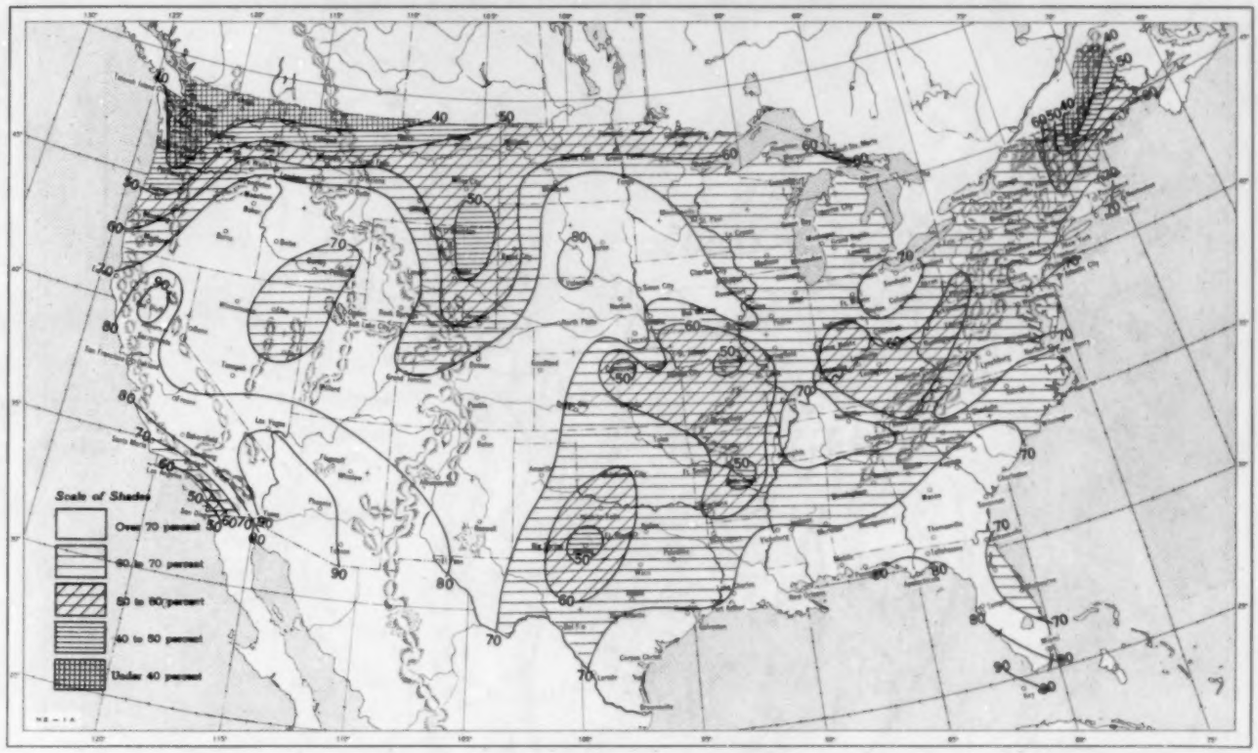


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, May 1955.

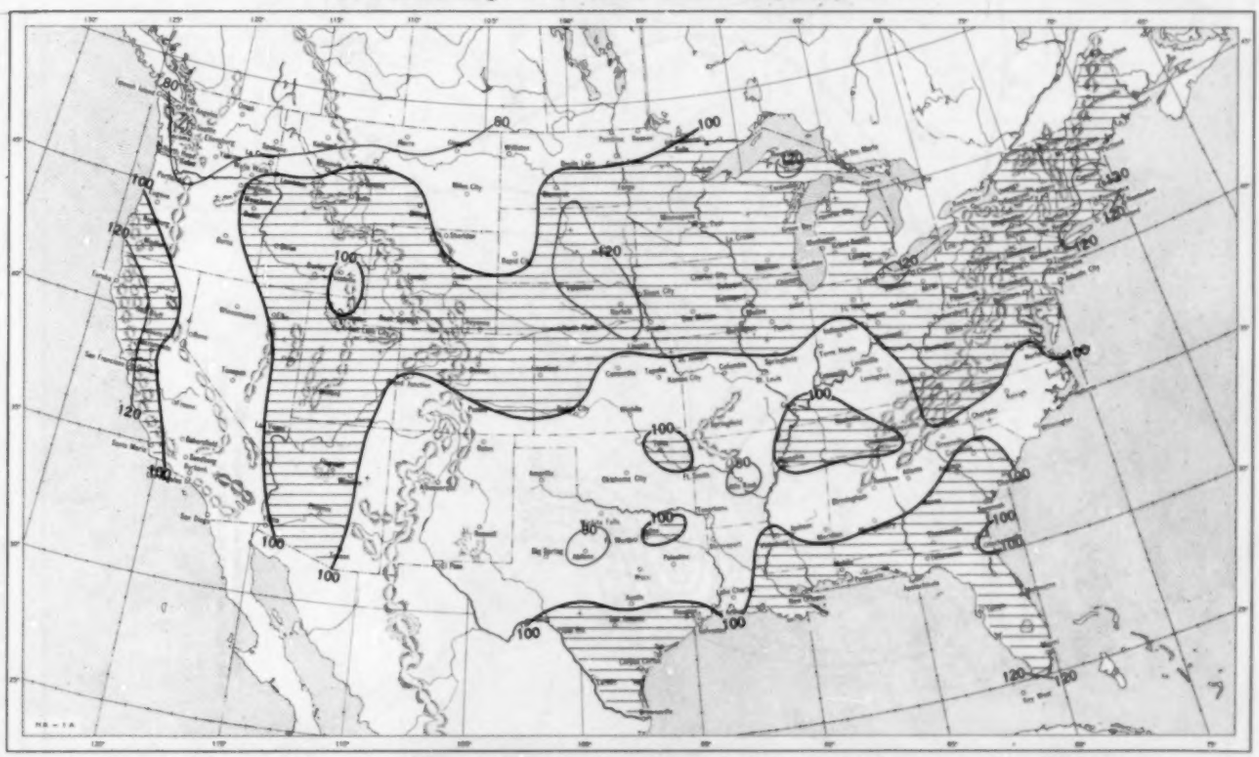


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, May 1955.



B. Percentage of Normal Sunshine, May 1955.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, May 1955. Inset: Percentage of Normal Average Daily Solar Radiation.

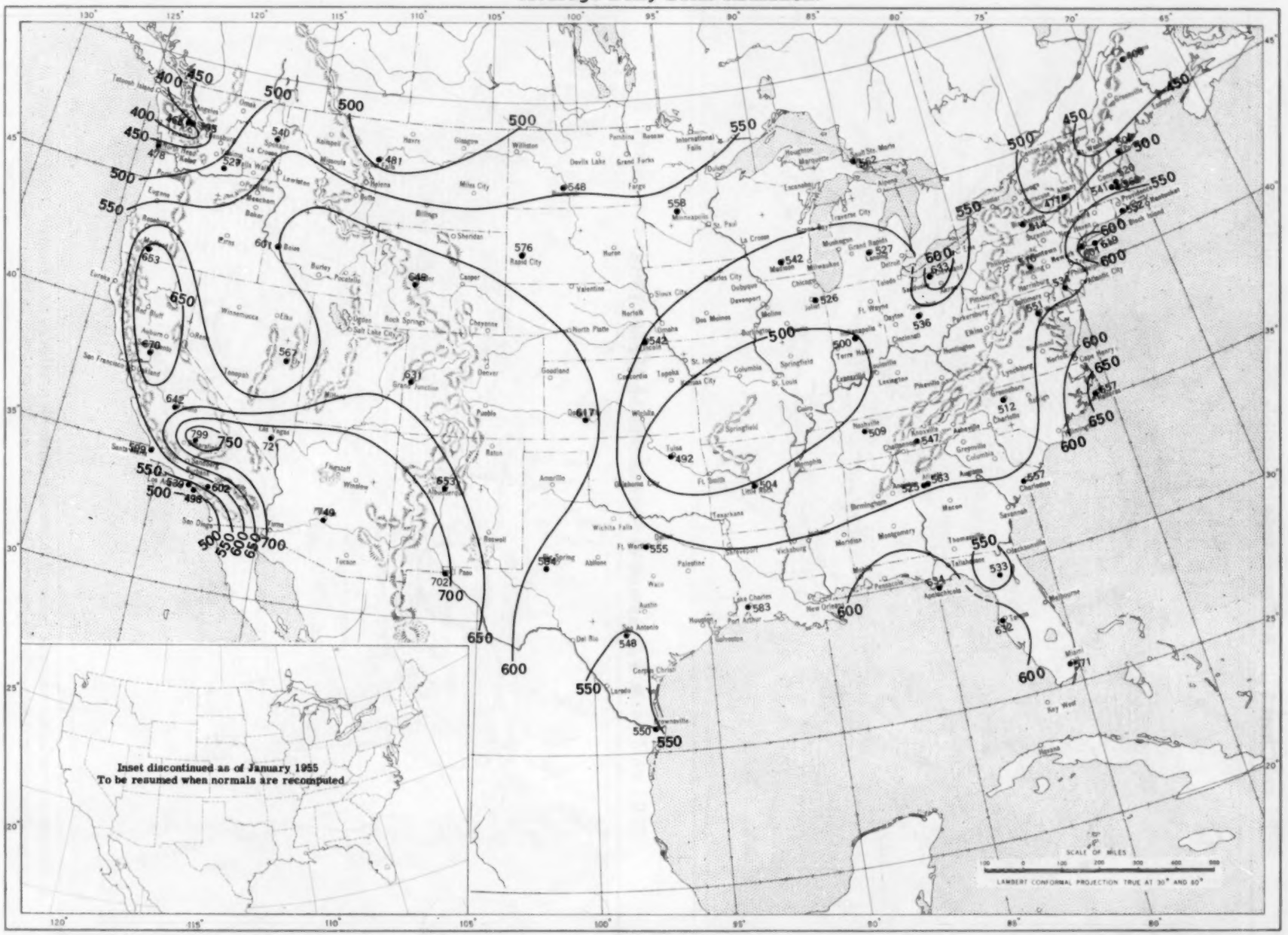
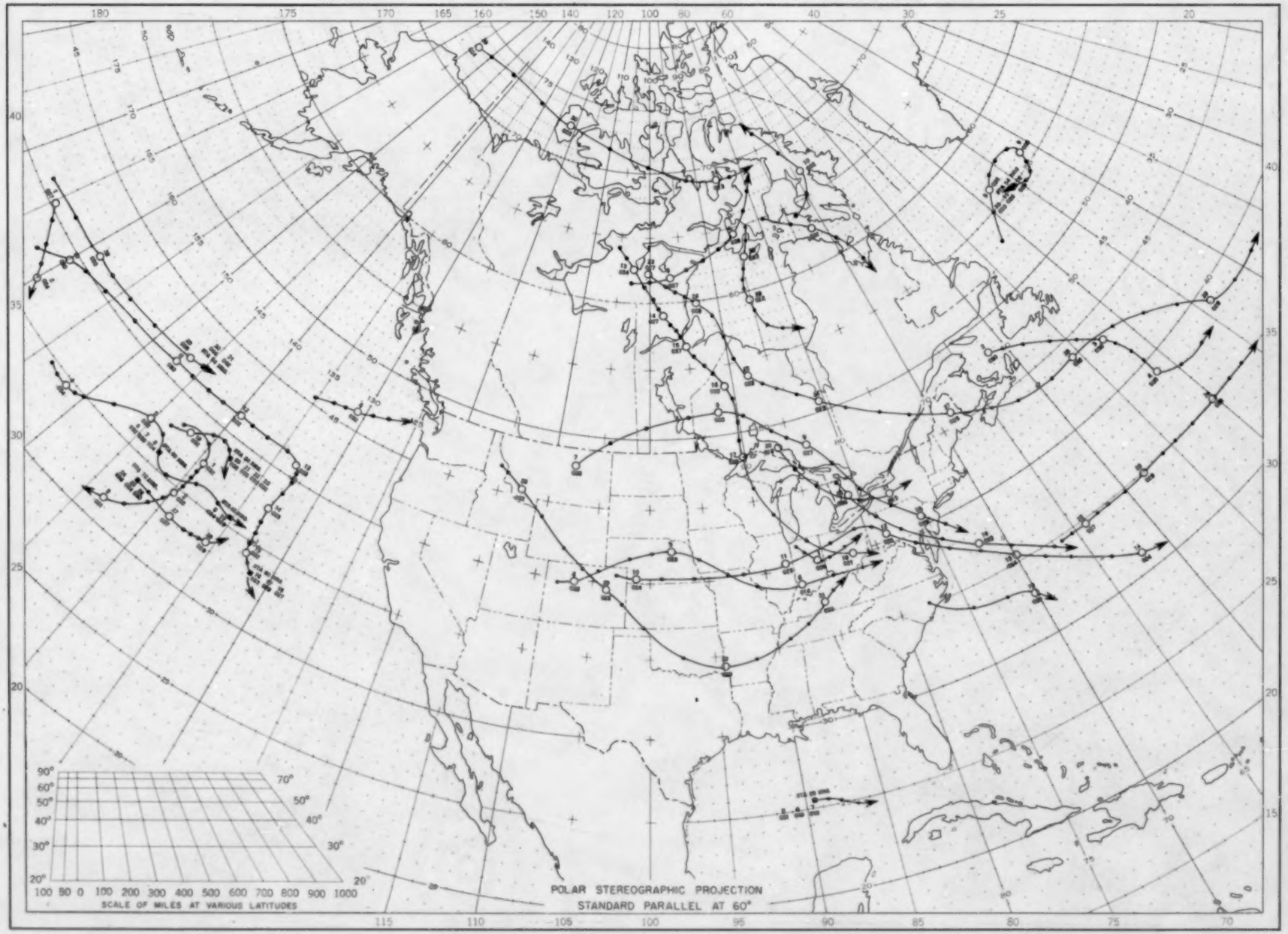

Inset discontinued as of January 1955
To be resumed when normals are recomputed
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION TRUE AT 30° AND 60°

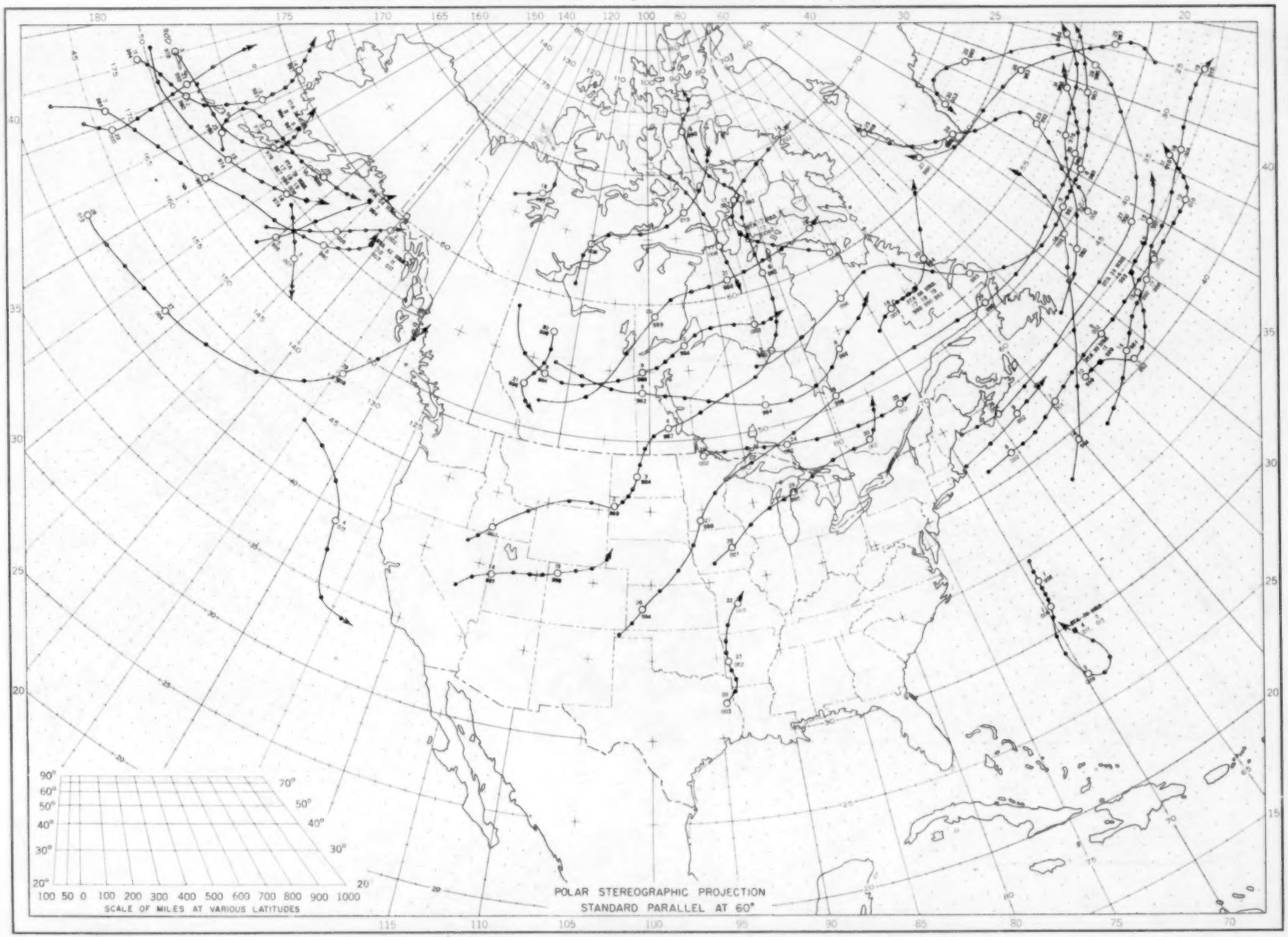
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, May 1955.


SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000
POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°

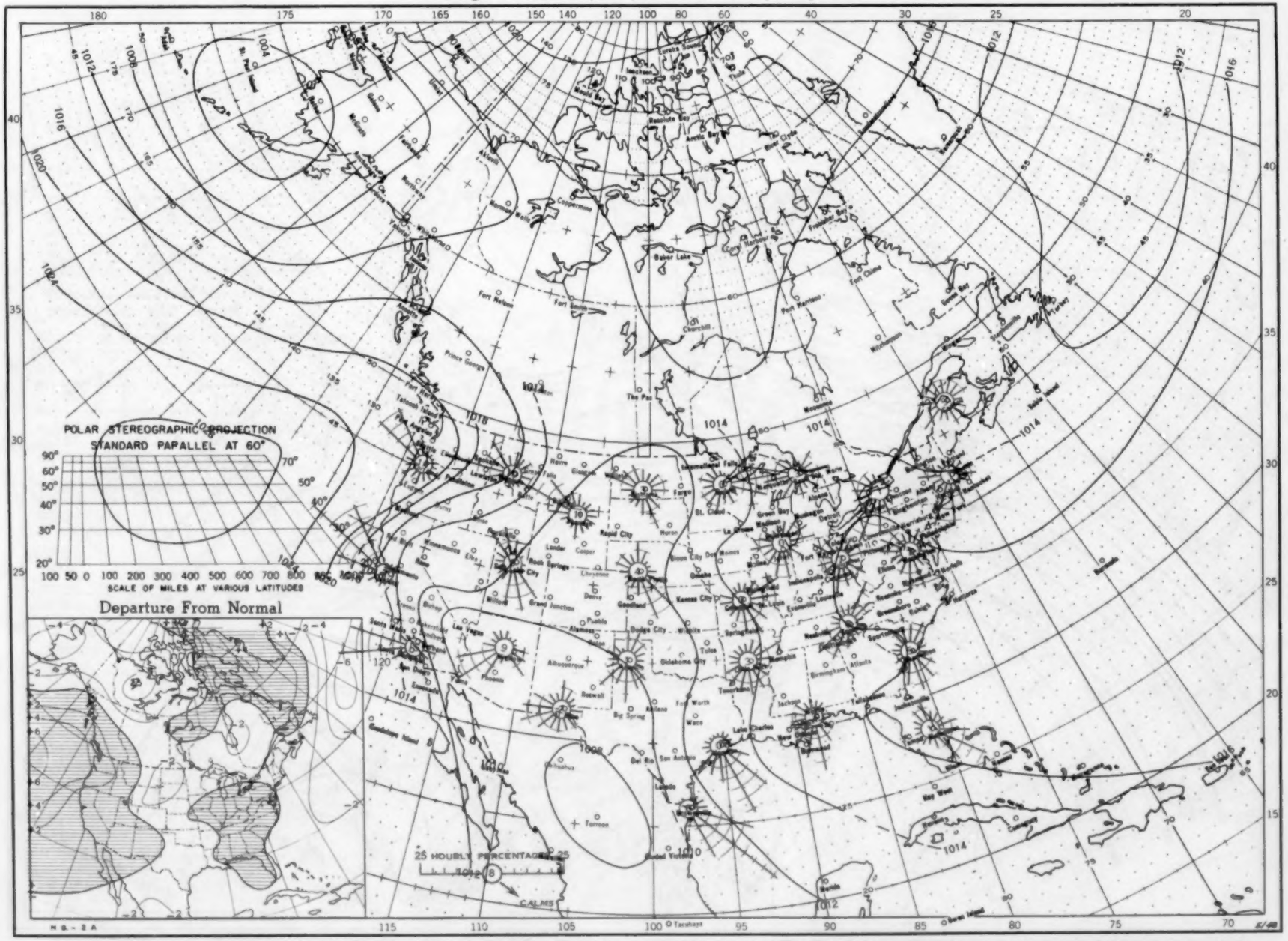
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, May 1955.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000

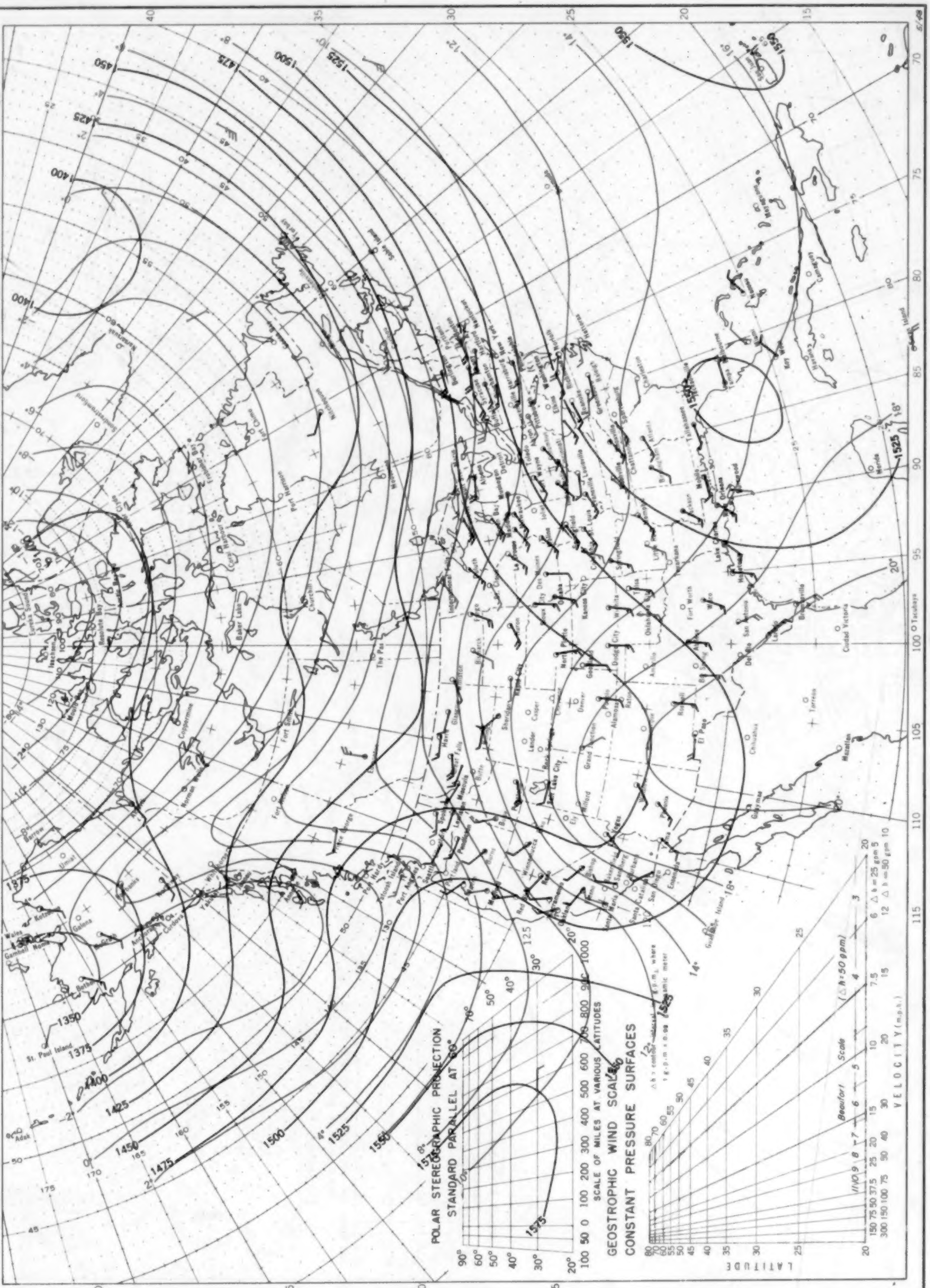
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, May 1955. Inset: Departure of Average Pressure (mb.) from Normal, May 1955.



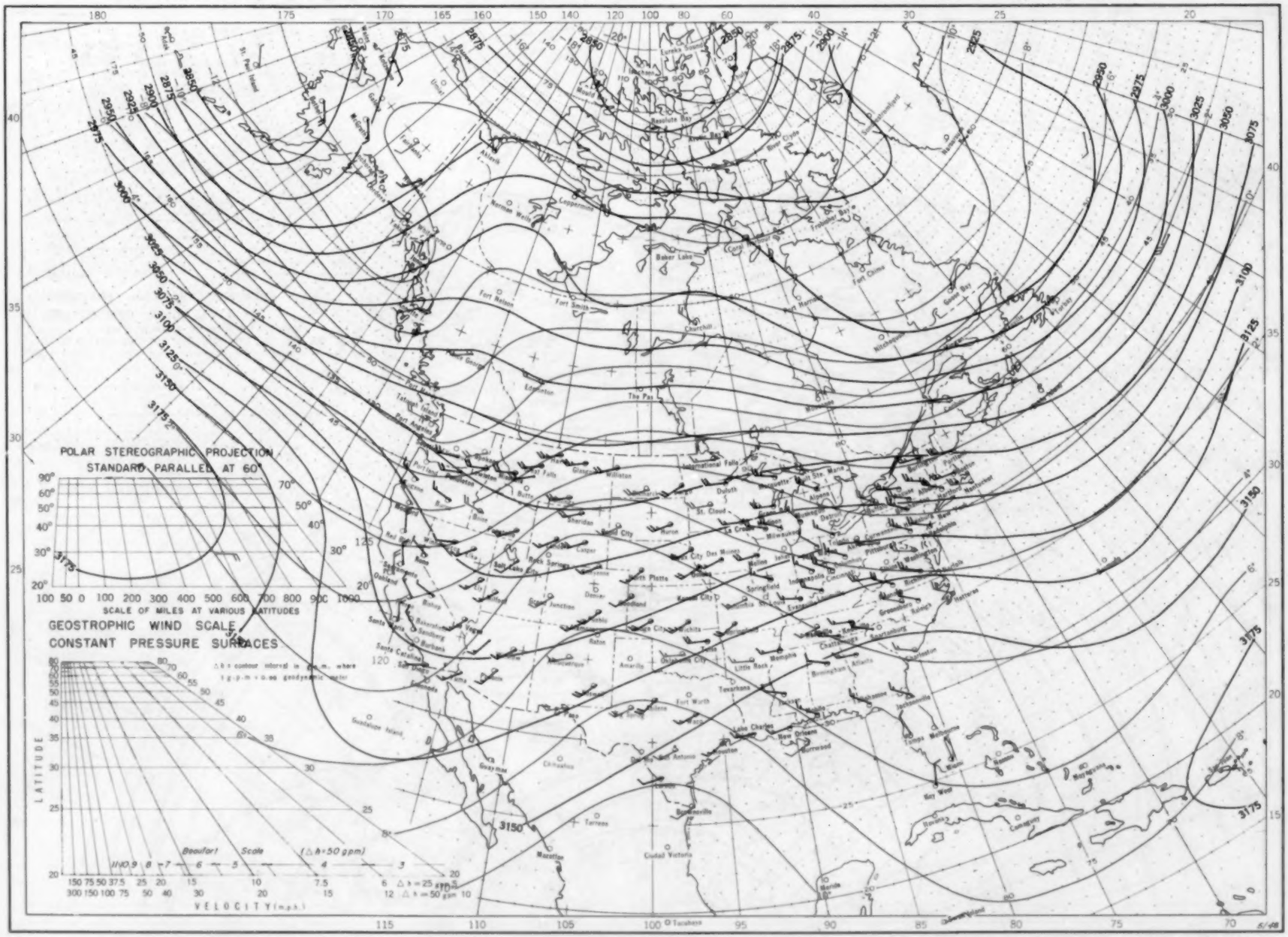
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), May 1955.



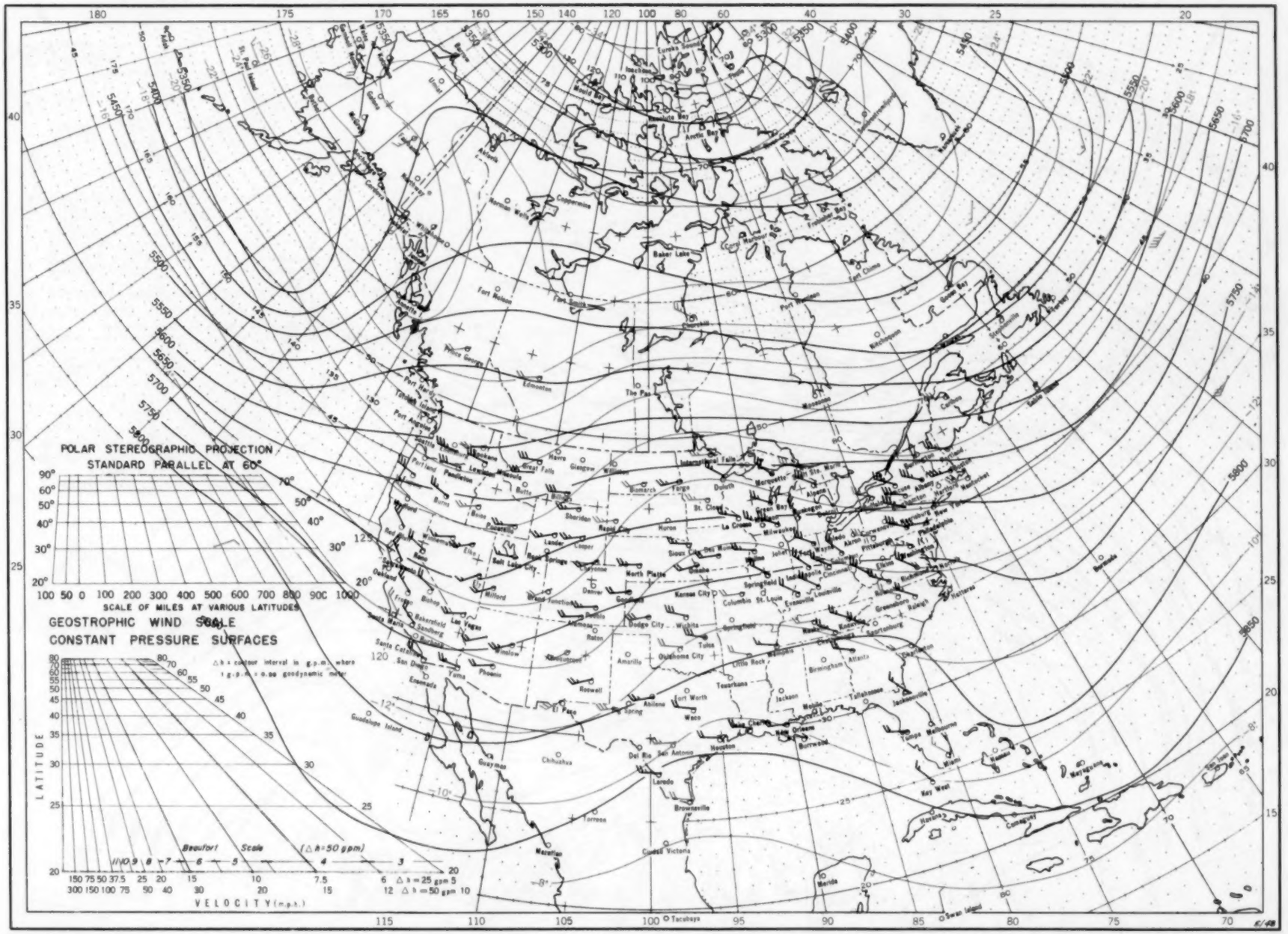
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m.. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), May 1955.



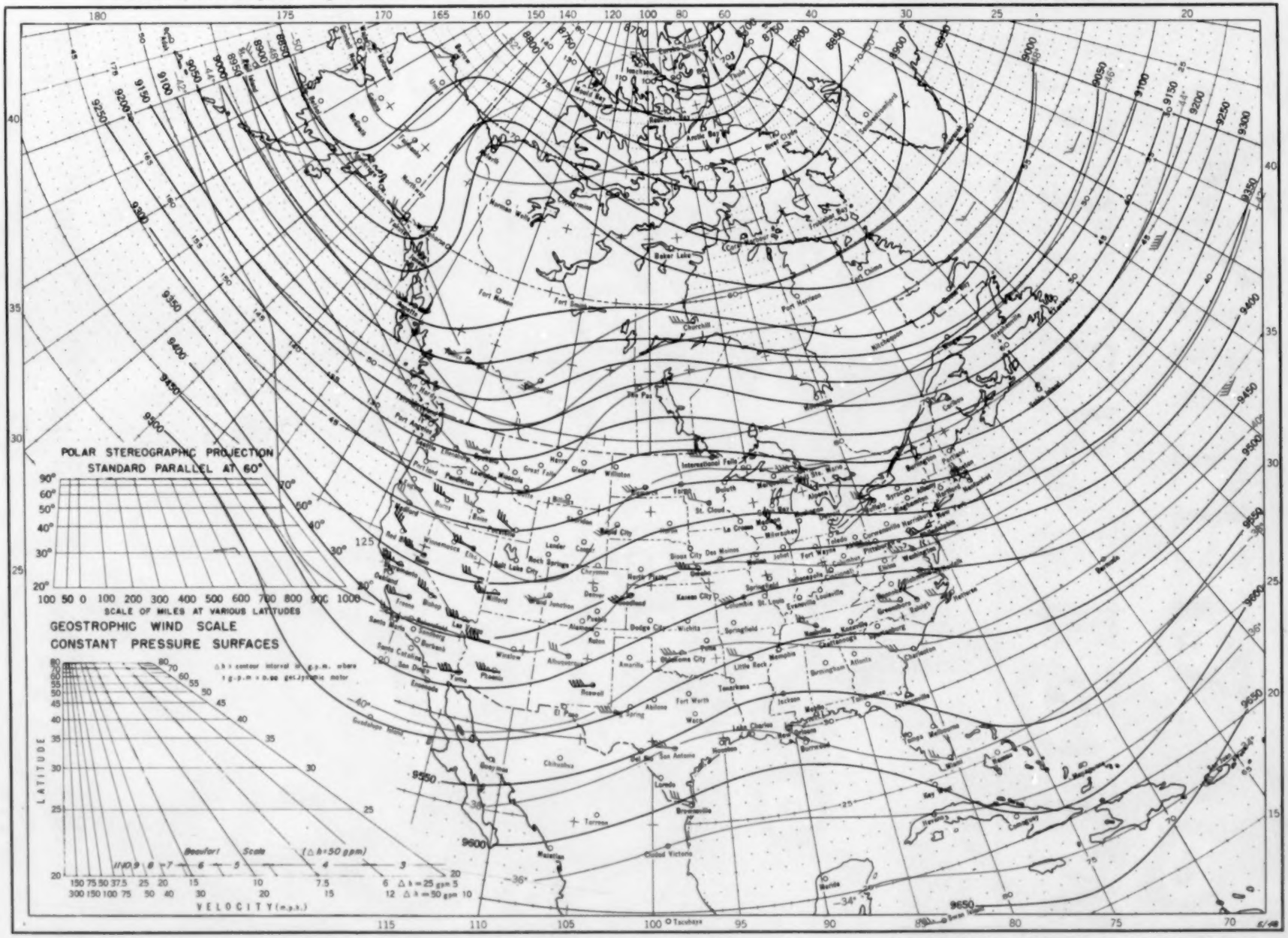
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), May 1955.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. those shown in red are based on rawins at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; Wind barbs indicate wind speed on the Beaufort scale.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), May 1955.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. those shown in red are based on rawins at 0300 G. M. T.

Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; Wind barbs indicate wind speed on the Beaufort scale.